INTERMEDIATE ZOOLOGY

By

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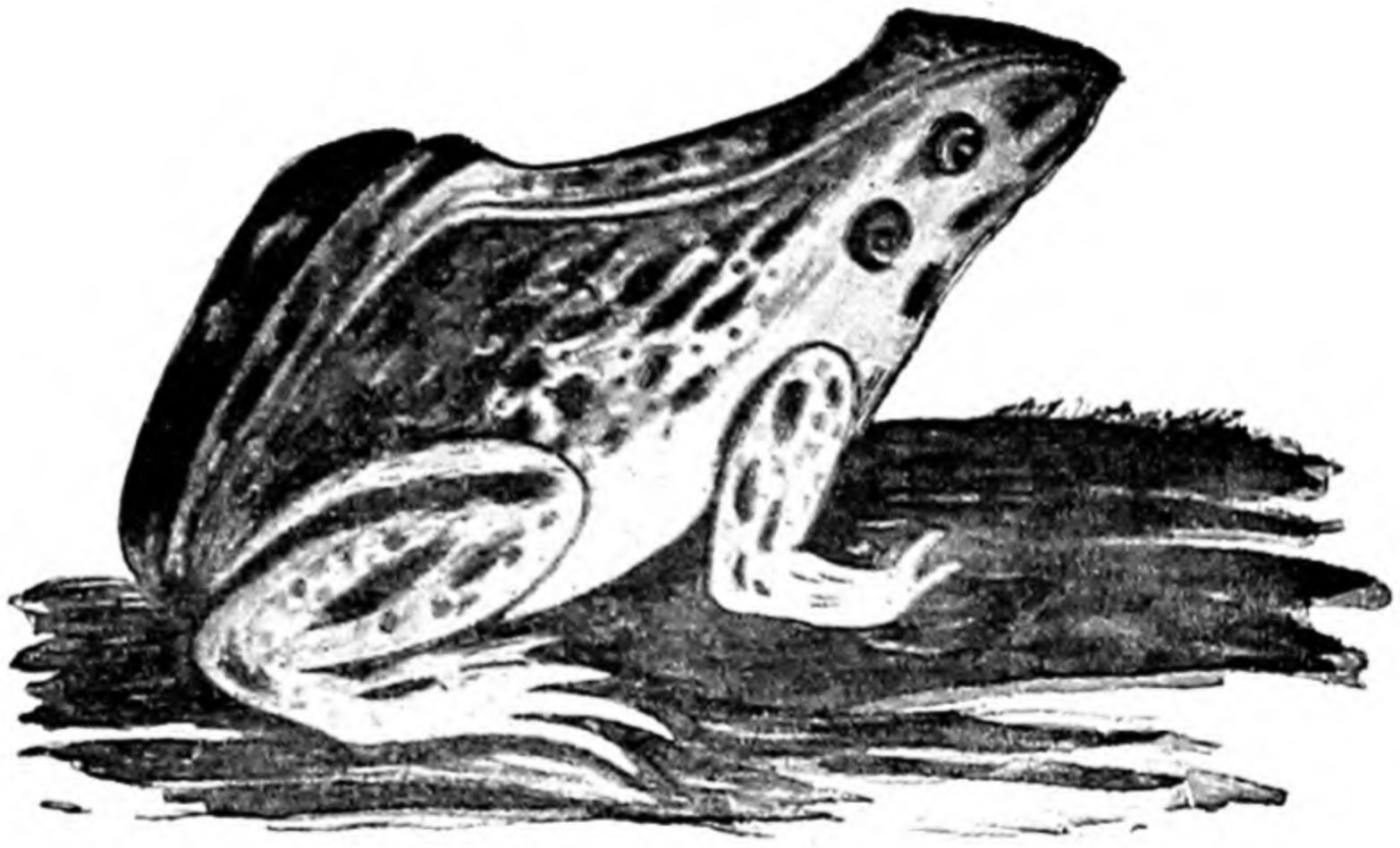

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PREFACE TO THE FOURTH EDITION

The book has been carefully revised, and brought up to date. Recent work on the circulation of blood through the frog's heart, and the early development of the frog, has been included. A number of new figures have been added.

I am grateful to the teachers of Zoology who have kindly sent to me many useful suggestions. These have been of great help in improving the book. I shall be glad to receive further suggestions and comments in the future.

On account of the continuous and great demand the book has been reprinted.

Civil Lines, Ludhiana,
August, 1961.

D. R. PURI

PREFACE TO THE FIRST EDITION

This elementary text-book of Zoology has been written for the use of the Intermediate students of the Punjab University and other Indian Universities. As Zoology is a new subject for the Intermediate students, particular care has been taken to make the language as simple and clear as possible. As far as practicable, each scientific term, when used for the first time in the book, has been explained or defined. In case the student fails to find the meaning of a term in the text he should turn to the Glossary at the end.

While teaching Zoology to the Intermediate classes one of the two plans of study may be followed. One may begin with the simplest forms, that is, **Amoeba** and **Paramecium** and, going progressively through the more complex forms, finish up with the rabbit. Or one may first take up the frog as an example of a typical animal and deal with the other forms later. It is the author's considered opinion that the latter plan is more suitable for the beginner, who

would more readily understand the various aspects of animal life from the study of the frog, which in many respects resembles man, than from the lower typical forms like **Amoeba, Paramecium** and **Hydra**. A fairly detailed account, therefore, of the anatomy, physiology, histology and embryology of the frog has been given in the book. This should form a sound foundation for further study of the subject.

It is, however, felt that certain fundamental biological facts should be understood before the student can proceed properly with the study of the frog. These are contained in the first three chapters, preceding the account of the frog, which covers the next fourteen chapters. After this, a chapter each is devoted to the other animal types prescribed for the Intermediate students. This is followed by a General Survey of the Animal Kingdom and General Zoology. It is suggested that the teachers should follow the plan as given in the book.

The book is profusely illustrated. Many of the figures have been specially drawn for this book and the rest have been taken from the works of the well-known authors, the source being acknowledged in each case. The new system of direct labelling, in which the complete name of each part is given alongside the figure, has been adopted. This will save much valuable time of the student. The figures have been drawn by Mr. R. L. Kapur who has done his best to make them neat and accurate.

The author would be grateful to fellow teachers if they will kindly send to him any suggestions which will make the book more useful for the Intermediate students.

Government College, Ludhiana. D. R. PURI
May, 1953.

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CHAPTER I

THE MEANING AND SCOPE OF BIOLOGY

Biology, Botany, and Zoology. *Biology* is the science of living things. It has two sub-divisions, namely, *Botany* which deals with plants and *Zoology* which is the study of animals. The subject of Zoology embraces not only those animals which are living on the earth at the present time but also those which lived in the past and have now disappeared or have become *extinct*. It deals with animals of the whole world whether they are found on land, in water or in the air. It includes man himself.

Branches of Zoology. An animal may be studied from various aspects. One may study its habits, structure, bodily functions, development, distribution, relationship with other animals and with its surroundings, past history or economic importance. There are, thus, various branches of Zoology and they have been given specific names. *Morphology* is the general term used for the study of the form and structure of animals. *Anatomy* deals with the structure of animals, more especially as revealed by dissection. *Histology* is the study of minute details of structure with the aid of the microscope. *Physiology* describes the bodily functions or the work which each part of the body does for the animal concerned. *Embryology* describes the development of an animal from the egg to the adult. *Taxonomy* deals with the classification of animals into groups. *Ecology* is the study of the relation of an animal with its surroundings. *Zoogeography* deals with the distribution of animals on the surface of the earth. *Palaeo-Zoology* is the study of the fossil remains of extinct animals. *Heredity* is concerned with the transmission of characters from parent to offspring. *Evolution* deals with the origin and differentiation of animals from pre-existing ones.

Study of Zoology. From the preceding paragraph it is evident that the subject of Zoology is very vast and varied. A student of Zoology, therefore, has to employ a variety of methods to study animal life in all its aspects. But whatever branch of Zoology he may be studying it is essential that he does so by direct approach to the animal concerned. It should be remembered that Zoology, like other natural sciences, cannot be learnt from books alone. The student should verify for himself the statements given in books by personal observation and experiment. This will entail both laboratory and field-work. In order to study, for instance, the structure of animals, which generally forms a considerable part of a course in Zoology, he shall have to work in the laboratory studying the actual specimens and dissecting them, if necessary. But there are certain aspects of Zoology, particularly those pertaining to habits, ecology, life histories and economic importance of animals which can be properly studied only by watching those animals living in their natural surroundings. Field-work, therefore, is an integral part of the study of Zoology. Fortunately, for the student of Zoology, there is ample scope for field-work in this country. There is hardly any place where some sort of animal life is not found. A keen student of Zoology should go about with eyes open to make observations on animal life around him. It would be true to state that the village boy who knows, by constantly watching, the habits and modes of life of the various types of animals found in his neighbourhood can claim to be a student of Zoology although he has never read any book on the subject.

Although there are various branches of Zoology it would be wrong to suppose that they have no connection with one another. The structure of an animal is always in accordance with its ways of life. A house-fly, a frog and a horse are so different from one another in their bodily structure yet each one of them is perfectly adapted to its particular mode of life.

Adaptation is a universal law of Biology. It plays an important part in the evolution of animal life. Its full significance would be understood at a later stage, but the student of Zoology should always keep in mind this basic law. In other words, he should always try to correlate structure with function. Similarly from the study of Embryology he should try to determine animal relationships which should ultimately provide clues to the evolutionary history of the animals concerned.

Importance of Zoology. The intimate relation that exists between man and animals is generally not so well recognized. It is beyond the scope of this book to go into a detailed account of the various aspects of that relation, but a brief outline of the various ways in which animals influence human life may be given here.

An important factor, bearing on the relation between man and animals, is that man himself, biologically speaking, is an animal. He is, thus an integral part of the animal kingdom. A child is keenly interested in living animals around him, and especially those, like the dog and the cow, which more or less resemble him. He finds in their behaviour a similarity with that of his own. The way two dogs fight over a piece of bread or a cow fondles her calf is fundamentally like human behaviour under similar conditions. Human interest in animals; therefore, is due to natural ties.

Apart from the instinctive urge that we have for observing animal-life, our interest is aroused from other motives also. Being a part of the animal community we are governed by the same general laws of Biology as the animals. We feed, grow, reproduce and eventually die as all animals do. The study of animal-life, therefore, helps us to understand, to some extent our own life. But our bodily structure and functions, and our reactions to various types of stimuli, bear greater resemblance to a certain class of animals than to others. A study of these higher animals has further solved many of the problems con-

nected with human life including the evolution of man. Innumerable experiments performed successfully on animals have proved equally successful in the case of man. Many important surgical operations have been made possible only by experiments on animals. It was not considered safe to perform them for the first time on human beings. Research on animals, like the frog, rabbit, rat and dog, has helped us to understand physiological processes in man and the action of various drugs on the human body.

There are many other points of contact between man and animals but all of them are not to his advantage. There are useful as well as harmful animals. One of the primary needs of man is food. A considerable part of it comes directly or indirectly from animals. Fish, meat, eggs, milk and honey are all animal foods. In addition to this direct supply of food, the bees and other insects are indirectly helping us to increase our food supply. These small creatures are daily pollinating the flowers of our vegetable and fruit crops without which their yield will be extremely poor. Animals also provide us with material to cover our bodies. Silk is produced by the silk-moth. We obtain wool from sheep and various types of furs from other hairy animals. Leather is another product which is used for various purposes. From glands and other internal organs of many animals useful medicines are prepared. Animals, like the ox aud the horse, come to our help in agricultural operations and transport. (It is difficult to imagine what our condition would have been without all these aids from the animal kingdc n.)

There is, however, a dark side of the picture also. Where thousands of bees are busy pollinating our flowers there are other insects destroying our crops. There is not a single type of crop which is immune from their attacks whether standing in the field or stocked in store-houses. The damage to our food by insects is colossal amounting to millions of rupees each

year. Not being content with this terrible mischief the insects cause various human diseases. The innocent-looking mosquito and the house-fly are the deadliest foes of humanity. The mosquito causes the malarial fever and the house-fly infects our food with germs of cholera, typhoid etc. The rat-flea carries the plague germs from the rat to man. All these diseases cause countless deaths. From malaria alone two million people die annually in India. There are other animals which enter the human body and grow there at his expense. These parasites, as they are called, include the round worms, flukes and tape-worms. There are still others which kill him outright. The poisonous snakes are responsible for over twenty thousand deaths a year in our country.

We, thus, see that human life is intimately bound up with that of animals. The study of Zoology, apart from imparting knowledge for its own sake, provides a means of understanding the precise relation between man and animals. The amount of success we achieve in reducing the ill-effects of that relation and enhancing its beneficial effects depends on the degree of understanding we have of animal-life. The study of Zoology, therefore, is intimately linked up with human welfare.

Living and Non-living Matter. Before we begin the study of animal-life it is essential that we know the properties of living matter in order to distinguish it from non-living matter. The chief properties of living matter are : (1) *definite size and shape*, (2) *growth*, (3) *respiration and excretion*, (4) *response to stimuli*, (5) *reproduction* and (6) *co-ordination of parts*

DEFINITE SIZE AND SHAPE. Living matter exists either as plants or animals. A particular kind of plant or animal has a definite size and a characteristic shape within certain limits. Frogs, for example, may differ somewhat in size and shape but they are uniform enough to be recognizable as frogs. Non-living matter, on the other hand, has no definite size or shape.

Water, for instance, may vary from a drop to an ocean and it may have any shape.

GROWTH. A living organism is able to take food and convert some of it into a part of its own body, thus increasing in size. This process is known as *growth*. It is a property of living matter to convert non-living food into living matter. In this process food-stuffs, which are chemically simple things, are digested and assimilated, and finally converted into *protoplasm* which has a very complex composition and which contains a large amount of dormant or potential energy. This constructive process of building up complex living matter, full of abundant potential energy, from simpler substances, with much less of such energy, is known as *anabolism*. Lifeless things like crystals, may also grow, but their growth is fundamentally different from that of living objects. They grow by a mechanical process and the new material is added on the outside. Mere increase in bulk is not growth in the biological sense.

RESPIRATION AND EXCRETION. *Respiration* is the process by which a living organism obtains oxygen from the surrounding medium. The oxygen combines with the protoplasm which breaks up into simpler substances. This results in the conversion of the potential energy of the protoplasm into active or kinetic energy and the formation of waste-products such as carbon dioxide and urea. By this energy the organism is able to perform all its functions. The waste-products, if retained inside the body, prove harmful and are, therefore, eliminated by various methods, the process being known as *excretion*. The destructive process of breaking down of the complex protoplasm, by the action of oxygen, into simpler substances with the liberation of energy and the formation of waste-products is known as *katabolism*. It is just the opposite of anabolism which is a constructive process. The two are collectively known as *metabolism*.

As energy is being constantly used up by a living organism,

in order to perform its life-functions, the protoplasm is being continuously destroyed as a consequence. To make up for this loss new protoplasm is being built up from the food that is taken. This process of destruction and construction, or metabolism, goes on ceaselessly throughout the life of the individual. It is, thus, evident that living matter is ever changing and the change is not due to any external physical cause but is inherent in the living matter itself. Non-living matter is inherently inert.

RESPONSE TO STIMULI. A living organism reacts in a particular way to changes in the surrounding conditions. The change in the environment which brings about a reaction is known as a *stimulus* and the reaction itself a *response*. The aim of the response to a stimulus is to adapt oneself to the changed condition. This property of living matter is more evident in animals than in plants but the eminent Indian scientist, Sir J.C. Bose (Fig. 1), has proved by experiment that plants, like animals, respond to external stimuli. He invented highly sensitive instruments to record responses which could not be perceived by the naked eye. Apart from the finer responses which can only be demonstrated by delicate instruments, plants exhibit some elementary responses connected with their nutrition and growth. Sun-loving flowers, like the sun flower, face the sun to get more light. The roots of plants spread

Fig 1 J.C. Bose

more where there is moisture and food. Non-living things may also react to changes in the environment. An iron rod expands when heated but it is a mechanical effect. It is not in the nature of an adjustment or adaptation to an environmental change.

REPRODUCTION. Living organisms have the power to produce other individuals of their own kind. This process is known as *reproduction*. In the lower forms of life the task is accomplished by a simple division of the organism into two, or by a number of individuals budding off from the parent. In the higher forms there are two parents, the male and the female Both of them take part in the reproductive process. The former mode of reproduction is known as *asexual* while the latter as *sexual*.

CO-ORDINATION OF PARTS. The body of a living organism is made up of a number of parts all of which work together for the good of the organism as a whole. Their functions, thus, are perfectly co-ordinated. Non-living objects do not exhibit such unified behaviour.

Plants and Animals. It is not so easy to make a clear-cut distinction between plants and animals as is possible in the case of living and non-living objects. The most obvious character of animals is that they can move about but there are a few plants which can move about and there are some animals which cannot. The latter, like the sponges, spend their lives fixed to other objects. In the simplest forms of life plants and animals practically merge into each other with the result that some forms, like the green flagellates, are considered plants by botanists and animals by zoologists. This close similarity between the lowest types of plants and animals is due to the fact that in the beginning there was one creation of life on the surface of the earth from which both plants and animals have originated. Most plants may, however, be distinguished from animals by (1) *manner of growth*, (2) *structure of cells*, and (3) *mode of nutrition*.

MANNER OF GROWTH Plants, generally, grow by the addition of parts, such as leaves and flowers, externally. In animals, on the contrary, growth is mainly internal although certain visible parts like feathers, hair or horns show a gradual increase in size.

STRUCTURE OF CELLS. Plant-cells usually have a thick cell-wall composed of cellulose. It gives rigidity to the cell. This accounts for the hard and woody nature of plant body. Animal-cells, on the other hand, have generally no cell-wall and, when present, it is thin and membranous. Animal-cells, thus, are flexible and capable of changing their shape. This property enables animals to perform movements of various kinds.

MODE OF NUTRITION. A character which is almost universal among plants is the presence in their bodies of a green colouring matter called *chlorophyll* which is absent in animals. Chlorophyll has the property of converting, in the presence of sunlight, carbon dioxide from the air, and water from the soil, into organic compounds known as carbohydrates. This process is called *photosynthesis* In this process the green plant takes in and re-arranges simple substances, largely devoid of energy, and infuses in them kinetic energy of the sun in a potential form. The excess of oxygen is liberated as a by-product. The organic compounds thus formed serve as food for the plant which makes use of them in the same way as animals do. In other words, the process of metabolism is the same in both plants and animals, but whereas plants manufacture their own food, animals, being devoid of chlorophyll, are incapable of doing so. Whatever type of food an animal takes, its ultimate origin is the green plant. The mode of nutrition involving the manufacture of complex organic compounds from simple inorganic chemical substances, as in green plants, is known as *holophytic*, whereas that requiring the ingestion and digestion of complex organic fool-stuffs, as in most animals, is known as *holozoic*.

CHAPTER II

PROTOPLASM

Biology has been defined as the "Science of life" But what is life ? A satisfactory answer to this question has not been found even up to this day. A frog which hops about, feeds on insects and avoids being caught is called alive. But when we kill it, say by the use of chloroform it ceases to perform any of the functions of a living animal and we call it dead. In this process life has presumably departed from it. But has it lost anything ? Our most delicate instruments have so far failed to detect it. Life at best may, therefore, be defined as the activities of living matter. This living matter is known as *protoplasm*. The bodies of all animals and plants are made up of protoplasm. It is aptly called the "*physical basis of life.*"

Physical Structure of Protoplasm. Living protoplasm is a clear, jelly-like substance, more or less resembling the white of an egg. Its structure cannot be made out with the naked eye. We can study it only with the aid of a miscroscope. As protoplasm is constantly changing, it has different appearances at different times. These differences may partly be due to the changes incidental to the killing of living protoplasm and staining it for microscopic study. A number of theories (Fig. 2) in regard to the structure of protoplasm have, thus, been advanced. According to the *alveolar theory* protoplasm appears like a foamy mass of bubbles or *alveoli* embedded in a more viscid medium. The *reticular* concept of protoplasm is that of a net-work or *reticulum* contained in a liquid medium. If instead of a net-work there are fibres, the appearance is described as *fibrillar*. The *granular theory* holds that minute

granules are distributed, more or less evenly, in a liquid medium.

The theory now generally accepted is the *colloidal theory*, according to which protoplasm is a complex colloidal system as distinguished from a crystalloid system. A *colloid* is a mixture in which comparatively large particles, generally larger than molecules, are suspended in a liquid medium. A *crystalloid*

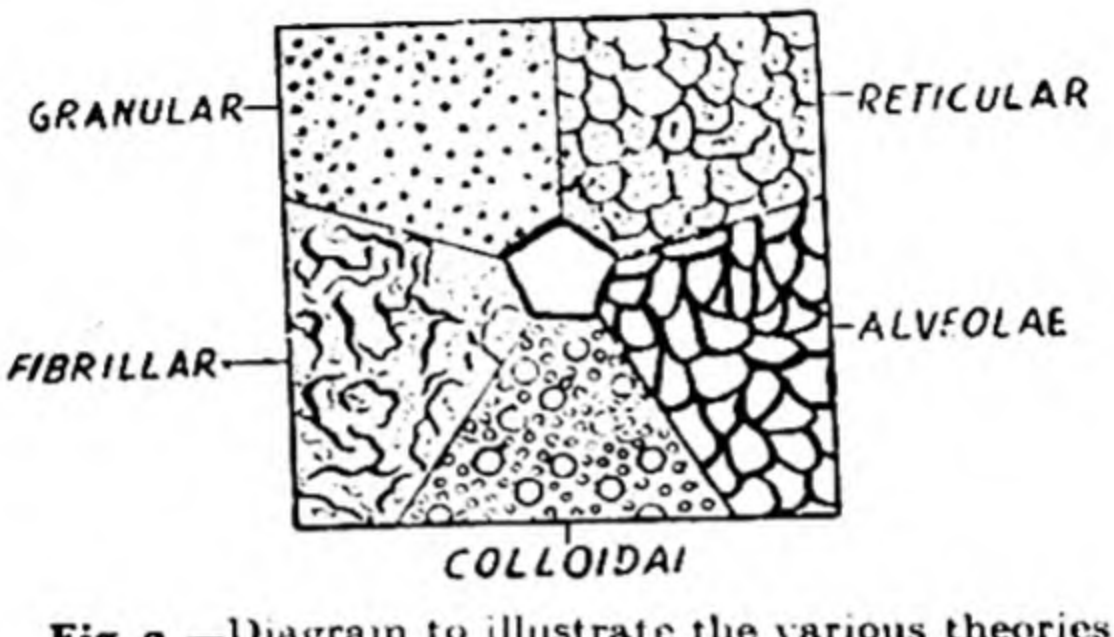

Fig. 2.—Diagram to illustrate the various theories of the structure of protoplasm.

is a true solution in which the suspended particles are in the form of molecules or ions. Salt solution is a common example of a crystalloid. Other properties which distinguish typical colloids from crystalloids are : (1) they are poor conductors of electricity, (2) they coagulate on heating, (3) they cannot produce osmotic pressure, and (4) they cannot be crystallized. All these are, thus, the properties of protoplasm.

The protoplasmic colloid may differ in consistency under different conditions. It may flow easily when it is said to exist as a *sol* or it may be more solid when it is called a *gel*. It may, however, change from a sol to a gel or from a gel to a sol. Such a colloid is known as a *reversible colloid*. The form it assumes depends upon the arrangement of the colloidal particles. When the particles are more or less evenly distributed in the liquid medium, the colloid flows easily and would be in the sol

condition, but when the particles are re-arranged so as to form a network, the meshes enclosing the liquid medium, the colloid changes to a semi-solid gel state.

Chemical Composition of Protoplasm. It is difficult to determine the exact chemical composition of protoplasm for. as soon as we attempt to analyse it, we kill it. Our analysis, therefore, relates to the dead and not the living protoplasm. Moreover, protoplasm does not have a fixed chemical composition as it is undergoing a constant change. And lastly certain compounds in the protoplasm are so complex that it has not so far been possible to analyse them fully.

A chemical analysis of protoplasm always yields carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, sodium, potassium, magnesium, calcium, iron and chlorine. In addition to these elements traces of silicon, manganese, copper, fluorine, bromine and iodine may occasionally be present. Of these elements carbon, hydrogen, oxygen and nitrogen constitute 90% of the whole mass. The various elements are not present in a free state but in the form of various compounds which are partly inorganic and partly organic.

Inorganic Compounds The inorganic compounds include *water* and *salts*. Water is by far the largest single constituent of protoplasm varying in amount from 60 to 90%. The protoplasm of plants contains more water than animal protoplasm. The chief function of water is to act as a solvent for the salts present in the protoplasm. The common salts found in the protoplasm are phosphates and chlorides of sodium, potassium, calcium, magnesium and iron. They are concerned with osmotic processes in the cell.

Organic Compounds. The most important of the organic compounds are the *proteins* as they are an essential part of living matter. Due to the presence in them of nitrogen, in addition to carbon, hydrogen and oxygen, they are commonly known as *nitrogenous compounds*. They coagulate on heating

and by the action of acids. Their molecules are relatively large and they diffuse very slowly through other substances. Common examples of animal proteins are *albumen* of egg, *casein* of cheese, *fibrin* of blood, *myosin* of meat and *gelatin* from hoofs of animals. Plant proteins include *legumin* of pulses and *gluten* of cereals.

The *carbohydrates* are composed of only three elements : carbon, hydrogen and oxygen. The ratio between hydrogen and oxygen is 2 : 1 as in water. They include starches, sugars, cellulose of cell-walls in plants and glycogen or animal starch, found chiefly in the liver. The sugars are soluble whereas the starches are not. The insoluble forms are generally stored as reserve food in both animals and plants. The carbohydrates have a great deal of potential energy which, on oxidation, is released as heat and other forms of energy.

The *fats* also are compounds of carbon, hydrogen and oxygen but the oxygen is relatively less than in the carbohydrates. They are, thus, capable of absorbing more oxygen and releasing more energy than carbohydrates. They are compounds of glycerine and one or more fatty acids into which they are decomposed when acted upon by alkalies. They have a greasy consistency and are insoluble in water. They are, consequently, suitable for being stored as reservoirs of food. They do not diffuse through the protoplasm but are found as suspended droplets.

The *lipoids* somewhat resemble fats as they are insoluble in water and soluble in fat solvents such as alcohol, ether and chloroform. They are mainly composed of carbon, hydrogen and oxygen but also contain some nitrogen and phosphorus. They have a waxy consistency. They are not broken up into their constituents by alkalies. They are abundantly found in the yolk of eggs.

CHAPTER III

THE CELL

Cell-theory. We have already learnt that the bodies of animals and plants are made up of protoplasm. This protoplasm, however, does not exist as a continuous and homogeneous mass but is organized to form unit masses, more or less like the bricks of a house, known as *cells*. A cell is, thus, the ultimate element of organic structure. This was first announced by Schloiden, a Botanist (Fig. 3) and Schwann, a Zoologist (Fig. 4), in 1838-39, and is known as the *cell-theory*. The word

Fig 3.—Matthias Schleiden.

Fig. 4.—Theodar Schwann.

cell means a small room or compartment. The plant-cells have generally thick walls and appear more like compartments than

do animal cells which have thin walls. But, as we shall learn later, the wall of the cell is of insignificant importance as compared to its contents.

Number of Cells. The number of cells in the body of an animal or plant varies with its size and age. The simplest organisms consist of a single cell and are known as *unicellular* while the rest, which consist of many cells, are called *multicellular*. Even a multicellular animal or plant begins life as a single cell. This first cell, the fertilized ovum, by repeated divisions becomes many cells. New cells can, thus, arise only from pre-existing cells. The multiplication of cells results in the growth of the individual. A fair-sized animal has millions of cells in its body.

Variety of Cells. Cells of living organisms have been compared to the bricks of a house, but a house cannot be built with bricks alone. Other materials like clay, wood, steel and cement are required. All these materials have their own specific properties and each is used to fulfil a particular requirement in the structure of the house. Similarly the body of an animal or plant has to perform various functions which are characteristic of living objects. The cells, consequently, become modified during development into various shapes sizes and consistencies. A detailed study of the different types of animal cells will be taken up at a later stage.

Cell-structure. A typical cell (Fig. 5) consists of a mass of protoplasm containing a central body known as the *nucleus*. The protoplasm of the cell outside the nucleus is known as *cytoplasm* while that constituting the nucleus as *nucleoplasm*. The cell is surrounded by a membrane, the *cell-membrane*, and the nucleus by the *nuclear membrane*. The outer boundary of the cytoplasm forms a *plasma membrane* just beneath the cell-membrane.

The nucleus contains a net-work of *linin* fibres to which are attached irregular masses of a substance called *chromatin*. This

substance derives its name from its property of staining more deeply with certain dyes than the other structures in the cell. Consequently the nucleus in a stained preparation appears deeper in colour than the cytoplasm. The meshes of the network in the nucleus are filled by a fluid, the *nuclear sap*. In addition to these structures, the nucleus contains one or more rounded bodies, the *nucleoli*, which are of various kinds. A true nucleolus or *plasmosome* stains lightly while another type, the *karyosome*, consisting of a mass of chromatin granules, stains deeply. The nucleus is the more important part of the cell. It plays the chief role in development and growth. It controls all metabolic activities of the cell. It is directly

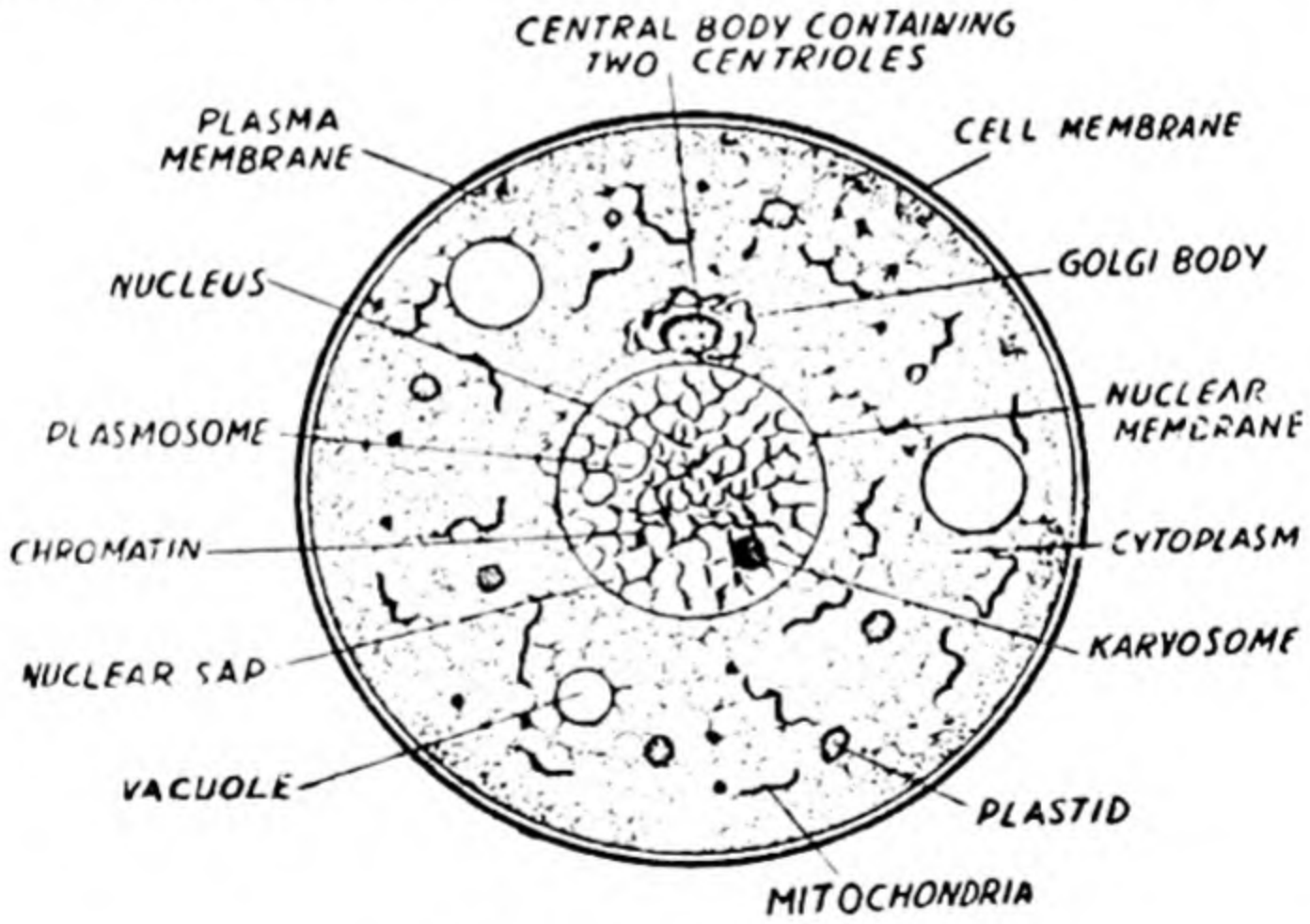

Fig. 5—A typical cell.

concerned with heredity or the transmission of characters from the parents to the offspring.

The cytoplasm is more homogeneous than the nucleus, being a clear viscid fluid. It contains two types of structures, namely, *protoplasmic* and *deutoplasmic*. The *protoplasmic*

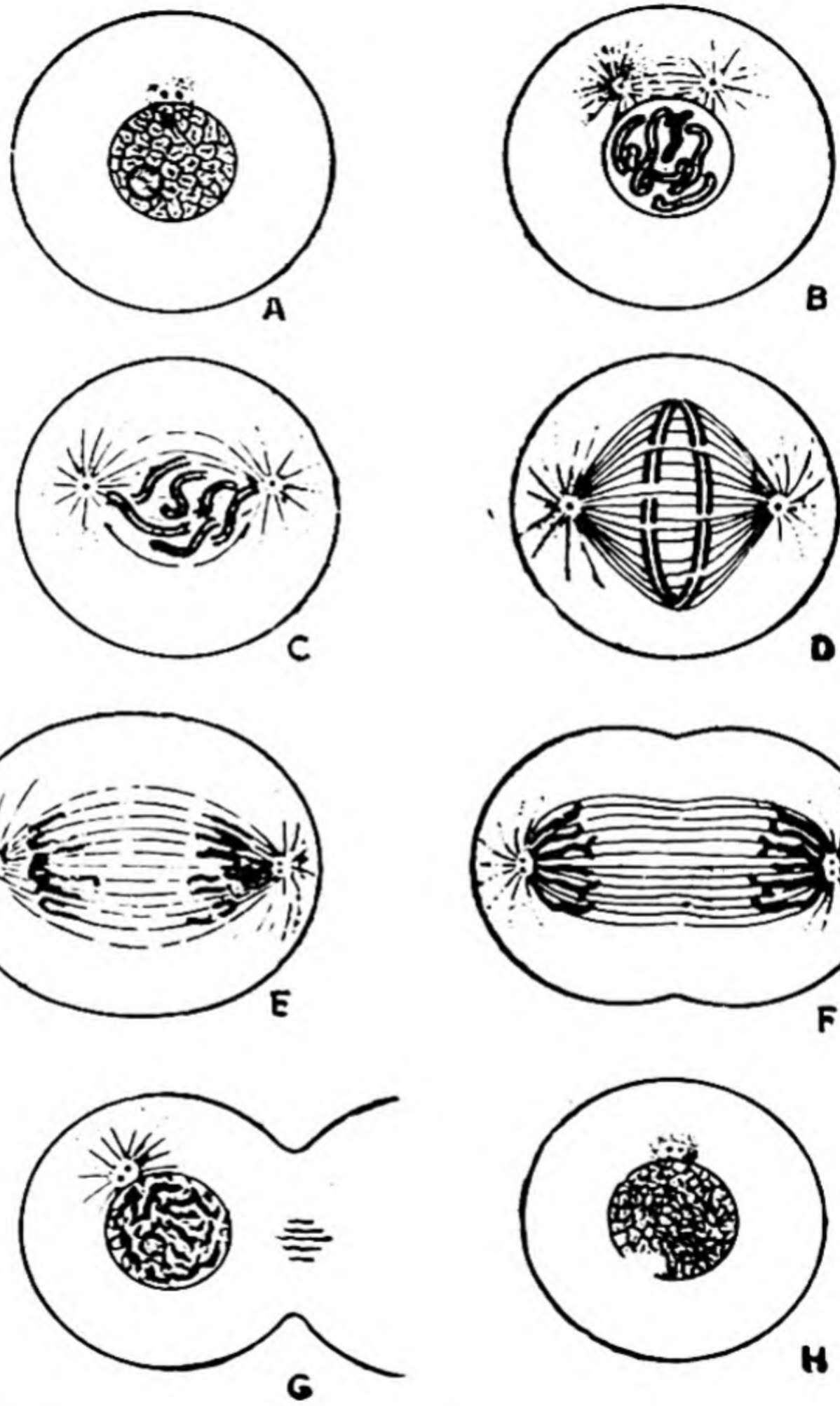

Fig. 6. Mitotic cell-division. A, resting cell before division ; B, prophase (early) ; C, prophase (late) ; D, metaphase ; E, anaphase ; F, telophase (early) ; G, telophase (late); H, resting cell after division.

longitudinally into two similar halves. The number of chromosomes is thus doubled.

ANAPHASE. The two chromosomes of each pair part company and gradually move along the threads to opposite poles of the spindle. Two groups of chromosomes are thus formed, each group containing an exact duplicate of each chromosome in the other group. The exact mechanism by which the chromosomes are drawn to the poles is not definitely known.

TELOPHASE. The two groups of chromosomes are now at their respective poles. Those of each group come together and unite to form a net-work. The nuclear membrane and the nucleolus make their appearance. Two daughter nuclei are thus constructed. In the meantime a constriction has appeared in the cytoplasm in the equatorial plane of the spindle. It gradually deepens and finally two new cells, each with a nucleus, are formed.

Gametogenesis. The body of a multicellular animal is composed of two categories of cells, namely, *somatic* and *germinal.* The somatic cells or the body-cells form the major part of the body and are concerned with the life of the individual animal. The germinal cells, on the other hand, are confined to the reproductive organs and give rise to the spermatozoa and the ova. They are concerned with the propagation of the species. The sperms and the ova, known as *gametes*, are formed by the differentiation of the primordial germ cells of the testis and the ovary respectively. The maturation of the gametes from the primordial germ cells is known as *gametogenesis* (Fig. 7). It consists of two processes, namely, *spermatogenesis*, in which sperms are formed, and *oogenesis*, in which ova are formed.

Spermatogenesis. The undifferentiated germ cells in the testis are known as *spermatogonia.* These contain the normal or *diploid* number of chromosomes. Let us suppose this number is eight in a given species The spermatogonia undergo a

normal mitotic division so that each daughter cell contains the same number of chromosomes as the parent, that is, eight. In this way a large number of spermatogonia is produced. Some of these become differentiated into large cells known as the *primary spermatocytes*, each containing the diploid number

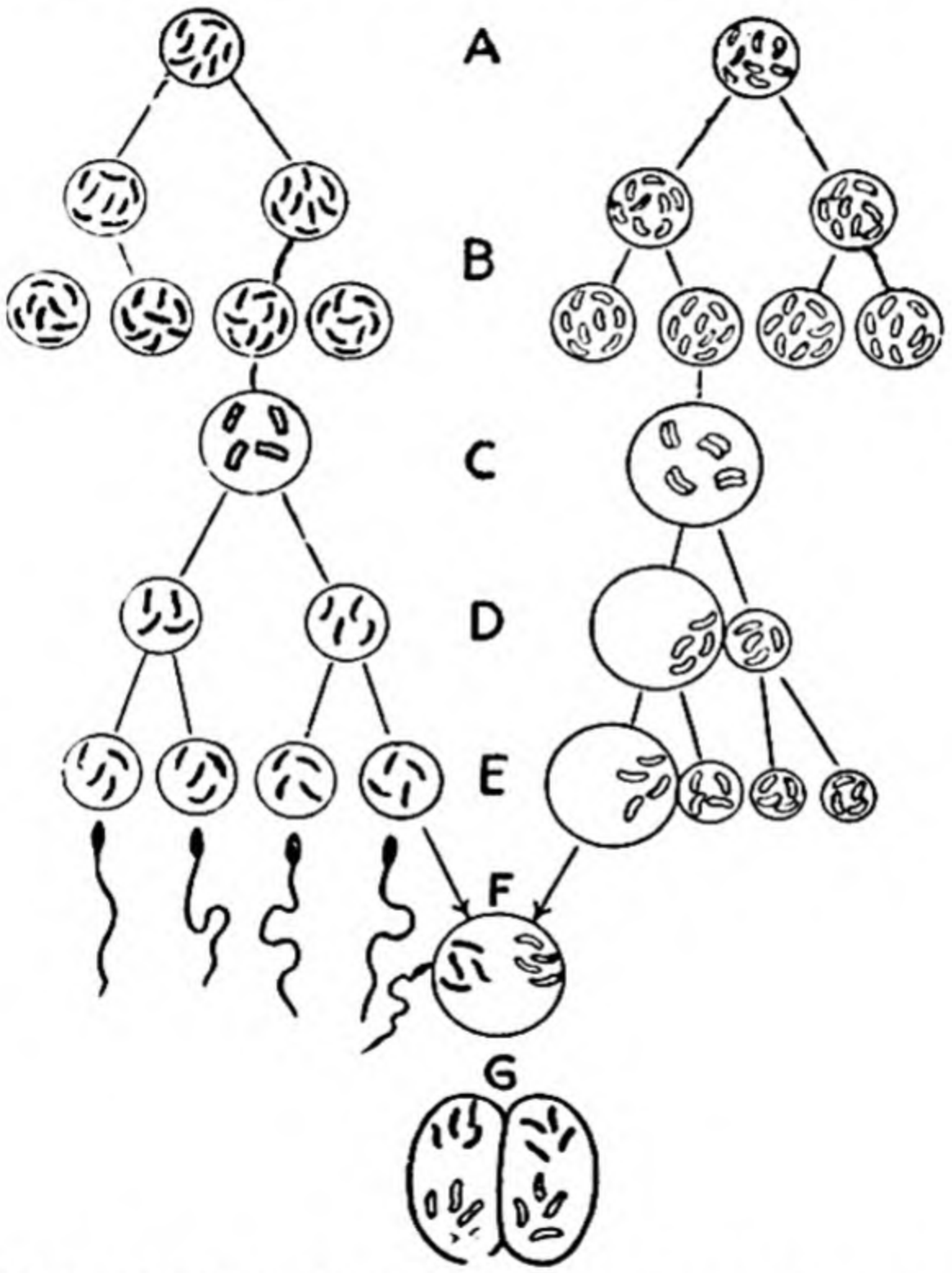

Fig. 7. Diagram to illustrate spermatogenesis (left) and oogenesis (right). A, primordial germ cells ; B, spermatogonia and oogonia ; C, primary spermatocyte and primary oocyte ; D, secondary spermatocyte and secondary oocyte ; E, spermatids, and egg and polar bodies ; F, fertilization ; G, division of zygote.

of chromosomes. Each primary spermatocyte now divides into two *secondary spermatocytes* in such a way that the latter come to possess half or the *haploid* number of chromosomes, that is four each. This division is, therefore, known as a *reduction division*, while the ordinary mitotic division, in which the daughter cells possess the same number of chromosomes as the parent cell, is known as an *equational division*. In a reduction division the eight chromosomes, instead of splitting into two each, come together to form four pairs at the equator of the spindle. This pairing of chromosomes during a reduction division is known as *synapsis*. One chromosome from each pair now travels to one pole and the other to the opposite pole. Each of the two secondary spermatocytes, thus, comes to possess four or haploid number of chromosomes. The process by which the number of chromosomes, during the maturation of gametes, is reduced to one half, is known as *meiosis*.

Each secondary spermatocyte divides into two *spermatids* by an equational division so that each spermatid has the haploid number of chromosomes, which, in the present case, is four. Each primary spermatocyte, thus, gives rise to four spermatids. The spermatids are gradually transformed into *spermatozoa*. Each spermatozoon has a head containing the nucleus and a long vibratile tail.

Oogenesis. Corresponding to the spermatogonia of the testis there are undifferentiated germ-cells in the ovary, known as the *oogonia*, each possessing the diploid number of chromosomes. The oogonia divide repeatedly by the ordinary mitosis till a large number of them is produced. Each oogonium grows into a large *primary oocyte*. During the period of growth yolk granules are generally deposited in the cytoplasm. The primary oocyte, like the primary spermatocyte, now undergoes a reduction or meiotic division but one of the two daughter cells is extremely small while the other is as big as the primary oocyte. The former is known as the *first polar body* and the

latter as the *secondary oocyte*, each having the haploid number of chromosomes. The secondary oocyte now divides equationally to form a large *mature ovum* and a small *second polar body* similar to the first. The first polar body also divides equationally to give rise to two small daughter cells like the parent. Each primary oocyte, thus, gives rise to three polar bodies and one mature ovum. The polar bodies degenerate and disappear. It should be noted that while a primary spermatocyte is converted into four spermatozoa, the primary oocyte produces only one mature ovum. The explanation for this is that all the cytoplasm and reserve food material, which would have been distributed among four cells if the divisions had been equal, are now accumulated in the single ovum for the proper nourishment of the growing embryo.

Significance of Reduction Division. The somatic part of the body of a multicellular animal is formed by repeated mitotic divisions of the fertilized ovum during which the number of chromosomes in each succeeding group of daughter cells remains the same as in the parent cell. If the number of chromosomes in the fertilized ovum is eight, then every somatic cell in the body will have eight chromosomes. We also know that the number of chromosomes for each species is fixed and remains so from generation to generation. If in the species with eight chromosomes there is no reduction division during spermatogenesis and oogenesis, the fertilized ovum, which is formed by the union of the sperm and the ovum, will have sixteen chromosomes eight from each gamete. In this manner the number of chromosomes in each succeeding generation will become double of the previous generation. In order to keep the number of chromosomes constant in each species there are reduction divisions during gametogenesis so that the sperm and the ovum come to possess only half the number of chromosomes each. After the union of the two the normal number is restored.

Fertilization. The union of the sperm and the ovum is known as *fertilization*. The spermatozoa swim about actively by means of their tails till one comes in contact with an ovum. The vitelline membrane of the ovum separates from the egg surface and at the point of contact a cytoplasmic protuberance, the *reception-cone*, is formed. Through this the sperm enters the ovum probably by the engulfing action of the latter but also partly, perhaps, by the boring motion of the former. The entry of one sperm causes a change in the ovum by which other sperms are prevented from entering it. The ovum is, thus, fertilized only by one sperm although many others may be found close to it. The nucleus of the sperm, which is now known as the *male pronucleus*, moves slowly towards the centre of the ovum. The nucleus of the ovum or the *female pronucleus* approaches the male pronucleus and the two fuse into one which is known as the *zygote nucleus* or *synkaryon*. Thus, strictly speaking, fertilization is the union of the male and the female pronuclei. The tail of the sperm does not take any part in the process of fertilization and soon degenerates. The fertilized ovum or the *zygote* by repeated divisions grows into the adult animal. This type of reproduction in which a new individual arises from the zygote, formed by the fusion of the male and the female gametes, is known as *sexual reprouction*.

Significance of Fertilization. As a rule the ovum does not develop into a new individual unless it is fertilized by a sperm. Fertilization, therefore, is essential for further development of the ovum. Moreover, as nuclear material is contributed equally by the male and the female parents, to form the zygote nucleus, the offspring inherits characters from both of them in equal degree.

Tissues. We have already learnt that the body of an animal is made up of cells. It has also been mentioned that the cells are of various kinds and that each kind is destined to play a specific part in the life of the individual. The size of a

cell is so small that it cannot by itself do much work for the animal concerned, except in the case of a unicellular organism. The cells of each kind, therefore, are grouped together, not necessarily at one place but usually at different places. Such groups of similar cells, with a common function, are known as *tissues*. The main kinds of tissues present in the body of a higher animal are *epithelial*, *muscular*, *skeletal* and *nervous*. A detailed study of these tissues would be taken up in a later chapter.

Organs. A number of tissues combine to form an *organ*. Thus the stomach is formed by epithelial, muscular, connective and nervous tissues. All these tissues assist the stomach to perform its digestive function. The stomach, therefore, is known as a *digestive organ*. Common examples of other organs are liver, heart, lungs, brain and kidneys.

System. As tissues combine to form an organ so a number of organs combine to form a *system*. Each system is concerned with a life-process or fundamental activity of the animal. The mouth, buccal cavity, oesophagus, stomach, intestine and the associated glands are all concerned with the process of digestion and assimilation of food. They together form the *digestive system*. Similarly the heart, arteries, capillaries and veins are concerned with the circulation of blood in the body. Hence they constitute the *circulatory* or *vascular system*. Other important systems are the *respiratory*, *excretory*. *skeletal*, *muscular*, *nervous* and *reproductive*.

CHAPTER IV

THE FROG

HABITAT AND HABITS

We have so far learnt something about the fundamental nature of living matter and how it is organized to build up the bodies of animals and plants. Let us now take up a specific animal and study it in some detail. For this purpose we would select the frog as it is easily available, is harmless and is of a convenient size. Moreover it is a fairly good representative of the higher animals, known as the *vertebrates*, whose common feature is that they all possess a back-bone. The study of the frog would give us a general idea of the various aspects of vertebrate life. The particular kind of frog which we propose to study is the common Indian frog, known by this name because it is common all over India. Its scientific name is *Rana tigrina*.

HABITAT

The natural home of an animal is known as its *habitat*. The habitat of *Rana tigrina*, like most other frogs, is in or near the water, whether it is a well, pond, lake or stream. The frog wants to live in the vicinity of water for various reasons. The most important of these is that it breathes partly through its skin. For this purpose the skin must be kept moist. From the edge of a pond or a stream the frog can jump into the water to moisten its skin. Another curious fact is that the frog does not drink water through the mouth, as we do, but all the water that it requires is absorbed through the skin and stored beneath it in cavities known as *sub-cutaneous lymph spaces*. For this purpose the frog has to be near the water. Water also protects the frog from its various enemies. As soon as it finds itself in danger of being attacked by an enemy, which may be

a snake or a bird, it escapes by plunging at once into the water. And finally there is an instinctive urge for the frog to be in the vicinity of water for it has spent its childhood in water and when adult breeds in water.

HABITS

Locomotion. *Locomotion* in the frog is effected by leaping or swimming, for which the long and well-developed hind-legs are admirably adapted. In either of these modes of locomotion the hind-legs are bent in the form of the letter Z and then quickly straightened. In the act of leaping the fore-limbs are used to absorb the pressure on the body caused by the fall of the animal on the ground. For swimming the webbed toes are an additional help. The fore-limbs, during swimming, are mainly concerned with keeping the body in the proper direction, although in swimming in an up and down direction they are used, to some extent, in propelling the body through the water.

Although the frog likes to be in water it cannot stay very long totally immersed in it for it must frequently come to the surface to breathe air. Sometimes the frog keeps floating near the surface of the water, in a relaxed condition, with only the tip of the snout exposed. Its body hangs obliquely downwards with the hind-legs partly extended and the fore-legs held out on the sides. It may lie in this position for considerable periods without performing any locomotory movements.

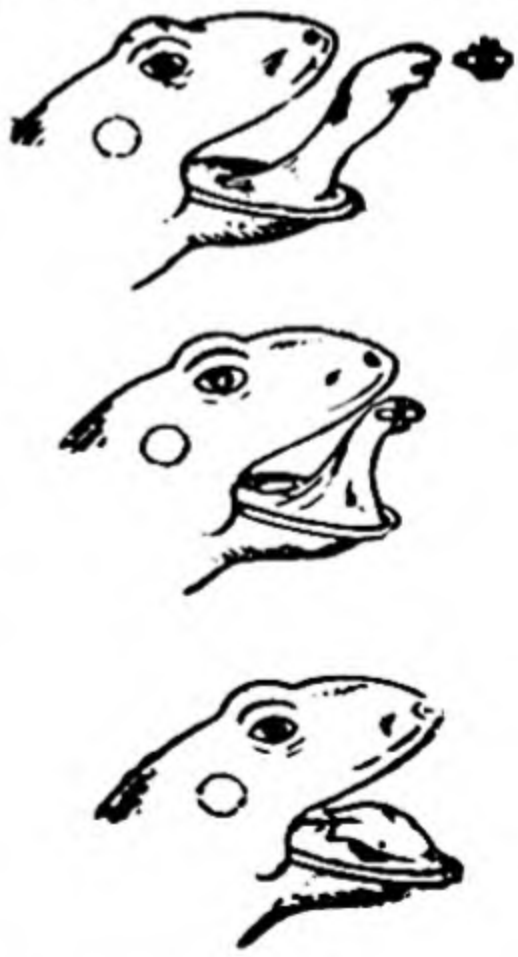

Fig. 8. The frog capturing its prey.

Food. The *food* of the frog consists of small creatures such as insects, spiders and earthworms. It is, thus, a *carnivorous* animal. The prey is captured

when it is moving. The mode of seizing the prey (Fig. 8) is characteristic. The tongue, which is attached to the mouth in front but is free and forked behind, plays the chief role in this operation. Its free hind end is thrown out with great rapidity so as to come in contact with the prey which adheres to it as the latter is covered with a sticky substance. The tongue is then instantaneously withdrawn to its normal position and the prey is devoured. There are small teeth along the margin of the upper jaw which prevent the escape of the prey.

Croaking. The *croaking* of frogs during the rains is familiar to every one. The male croaks more loudly than the female. This is due to the presence, in the male, of a pair of distensible sacs, one on either side of the throat, known as the *vocal sacs*. They help to raise the pitch of the croak. The croaking of frogs appears to be a call for mating which generally takes place during the rainy season.

Amplexus. Mating among frogs takes place in water. During this act the male mounts the back of the female clasping her firmly just behind the fore-legs. The clasp is strengthened

Fig. 9. The palm of the right hand. A of a male frog at the breeding season, B of a female, C of a male out of the breeding season. (From Borradaile).

by a pair of black swellings, the *copulatory pads*, on the index fingers of the male (Fig. 9). These pads are formed during the breeding season only.

In this sexual embrace, known as *amplexus*, the couple remains for many days. It moves about in the water, the burden of swimming falling mainly on the female. The pairing continues till the female lays the eggs over which the male pours the spermatic fluid. Fertilization of the eggs, then, takes place. After this the parents pay no attention to the eggs or the young which hatch out from them. Amplexus among amphibians should be distinguished from *copulation* among other groups, such as insects, birds and mammals, in which the sexual union between two individuals involves the transference of spermatozoa from the male to the female.

The baby frog is known as a *tadpole*. It resembles a fish more than a frog. It has no limbs but possesses a long tail by which it swims about in the water. It breathes by gills. It feeds on water-plants and is, thus, *herbivorous* in its diet. The tadpole grows in size and is gradually converted into the adult frog which leaves the water and comes out on land. We will learn, at a later stage why, unlike the human baby, the tadpole is so different from its parents.

Hibernation. The frog is a *cold-blooded* animal, that is, the temperature of its body varies according to the surrounding medium. It cannot bear the severe cold of the winter season, and to protect itself from the frost it buries itself deep in a damp place. It lies there throughout the winter in a dormant condition known as the *winter-sleep* or *hibernatian*. During this period it does not make any movement. The mouth remains closed and the feeding is stopped. Breathing takes place only through the skin. The frog obtains whatever little energy it requires from the store of glycogen in the liver and the fat in the fat-bodies. At the approach of spring it wakes up from its winter-sleep and comes out from its retreat to lead an active life again.

CHAPTER V

THE FROG (*continued*)

EXTERNAL CHARACTERS AND GENERAL INTERNAL STRUCTURE

External Characters. The body of the frog (Fig. 10) consists of the *head*, *trunk* and two pairs of legs or *limbs* attached to the trunk. The neck and tail are both absent. The body has a *bilateral symmetry*, that is, it can be divided into two exactly similar halves by a longitudinal cut along the middle line of the back.

Before we proceed any further it is necessary to know a few simple zoological terms relating to the four surfaces and the two ends of the frog's body The upper surface is known as *dorsal*, the lower as *ventral* and each of the two sidas as *lateral*, The front end is the *oral* or *anterior* and the hind end is the *aboral* or *posterior*

The *head* is flattened and roughly triangular in outline with a wide *mouth* in front. There are two small apertures, on the top of the anterior end of the snout, known as the *nostrils* or the *external nares*. Some distance behind the nostrils is a pair of large prominent *eyes*. As the frog has no neck it cannot turn the head around. The large bulging eyes, situated laterally on the head, enable it to look in all directions even without a mobile neck. In the centre of the eye is a dark oval area, the *pupil*, surrounded by a coloured ring, the *iris*. Each eye is provided with three *eyelids*. The *upper eyelid* is well developed but is only slightly movable. The *lower eyelid* is rudimentary and altogether immovable. The *third eyelid* or the *nictitating membrane* is a prolongation of the lower eyelid. It is more or less transparent and is freely movable. It can be drawn up to

completely cover the eye which is thus protected from the mud in the water. As it is transparent the frog can see even when its eyes are closed. In man the nictitating membrane is represented by a mere fold of the skin in the inner corner of the eye.

Behind each eye is a large dark area in the centre of which is a circular membrane known as the *tympanic membrane* or *tympanum*. It is a part of the ear. In the human ear the tympanic membrane is situated in the head at the inner end of the ear canal which opens to the outside in the centre of the external ear. In the frog both the canal and the external ear are absent and the tympanic membrane has come to lie in level with the surface of the body.

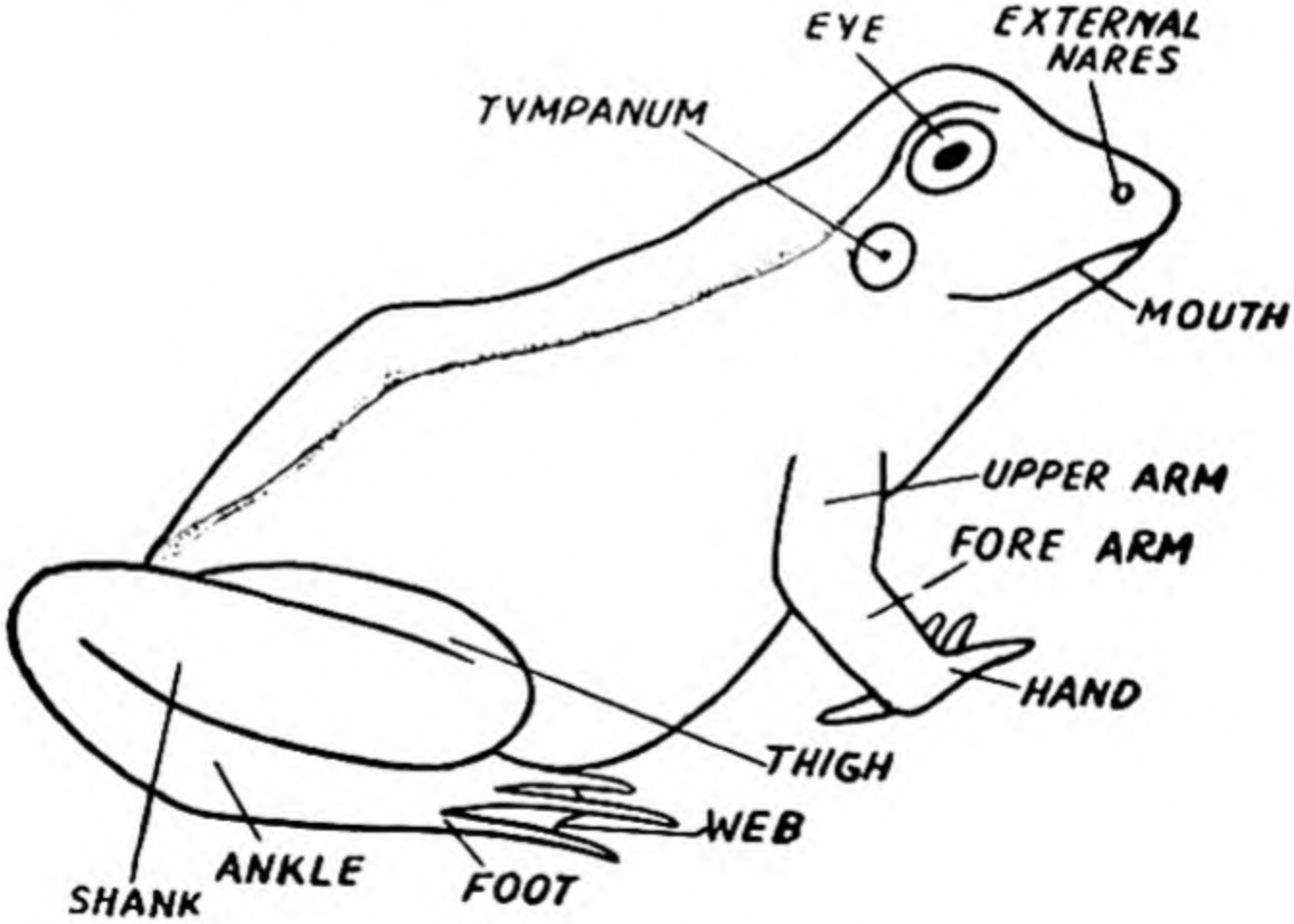

Fig. 10. External charactors of a frog.

The *trunk*, which is continuous with the head, is broad and somewhat flattened. When the frog is squatting, a characteristic hump is formed on the dorsal surface of the trunk. There is a common aperture, at the posterior end of the trunk,

for the discharge of the faeces, urine and the reproductiue elements. This is known as the *cloacal aperture.*

The two pairs of *limbs* have the same plan as our own. The *fore-limbs* are shorter than the hind-limbs and each consists of three parts. The proximal part, or the one nearest the trunk, is the *upper arm*, the middle one is the *fore-arm* and the distal one, or the one farthest from the trunk, the *hand* or *manus.* The hand consists of the *wrist, palm* and four *fingers.* The *thumb* or *pollex* is absent but its rudiment can be felt under the skin. As already noticed the male frog acquires, during the breeding season, a *copulatory pad* on the first or the index finger of each hand.

The *hind-limbs* are much longer and more powerful than the fore-limbs. They, like the fore-limbs, are divided each into three parts, namely, the proximal *thigh*, the middle *shank* and the distal *foot* or *pes.* The foot consists of the *ankle*, *instep* and five *toes.* The ankle is elongated. The toes are webbed. The fingers and toes are also known as *digits.* Thus the frog has four digits in the hand and five in the foot.

The *skin* of the frog is soft and slimy, and is devoid of scales, feathers or hair. It is loosely attached to the underlying muscles. Its dorsal surface is olive or dusky green mottled with dark spots and patches of varying sizes. The ventral surface is almost white. A remarkable thing about the skin is that its colour does not remain constant but frequently changes so as to harmonize with its surroundings. If a frog is kept in a dark place its colour becomes very dark while in bright daylight it becomes much lighter. It is a device by which it conceals itself from its enemies. This phenomenon is known as *protective colouration.* The skin has on the outside a thin transparent membrane which is periodically cast off. This process is known as *moulting.* The entire membrane is not shed at one time but in small pieces.

General Internal Structure. We have noted above

that the body of the frog is covered by the slimy skin. Beneath the skin is a layer of muscles to which the former is loosely attached by means of thin bands of connective tissue. The spaces thus left are the *sub-cutaneous lymph spaces*. The various bones of the body, collectively known as the *skeleton*, are embedded in the muscular layer. The well-developed muscles of the back enclose the *backbone* or the *vertebral column*, which consists of a number of pieces, the *vertebrae*. As the vertebrae are ring-shaped and arranged end to end, they enclose a long cavity, the *vertebral canal* which lodges the main central nerve, the *nerve cord* or the *spinal cord*. The vertebral column is connected in front with the bony part of the head known as the *skull*. The latter encloses the *brain*, and the *organs of hearing* and *smell*. The brain is continuous behind with the spinal cord. In the anterior and the posterior regions of the trunk are two bony structures known as the *shoulder-girdle* and the *hip-girdle* respectively. They provide points of attachment and articulating surfaces for the limb-bones, which are embedded in the limb-muscles. Most of the muscles are attached at the two ends to the bones by means of tough bands known as *tendons*. This enables the animal to make various kinds of movements.

The trunk contains a large cavity, the *body-cavity* or *coelom*. It contains most of the soft organs of the body such as the heart, stomach, intestine, liver, spleen, lungs and gonads. All the soft organs in the body-cavity are collectively called the *viscera*. The body-cavity is lined by a membrane the *peritoneum*. The body-wall, thus, consists of the skin, muscles and the peritoneum. Each of the internal organs is enclosed within an extension of the peritoneum by which it hangs, so to say, inside the body-cavity. The peritoneum from the two sides of each organ meets on the dorsal side to form a double fold which in the case of the organs of digestion is known as the *mesentery*. Two parts of the peritoneum may, thus, be

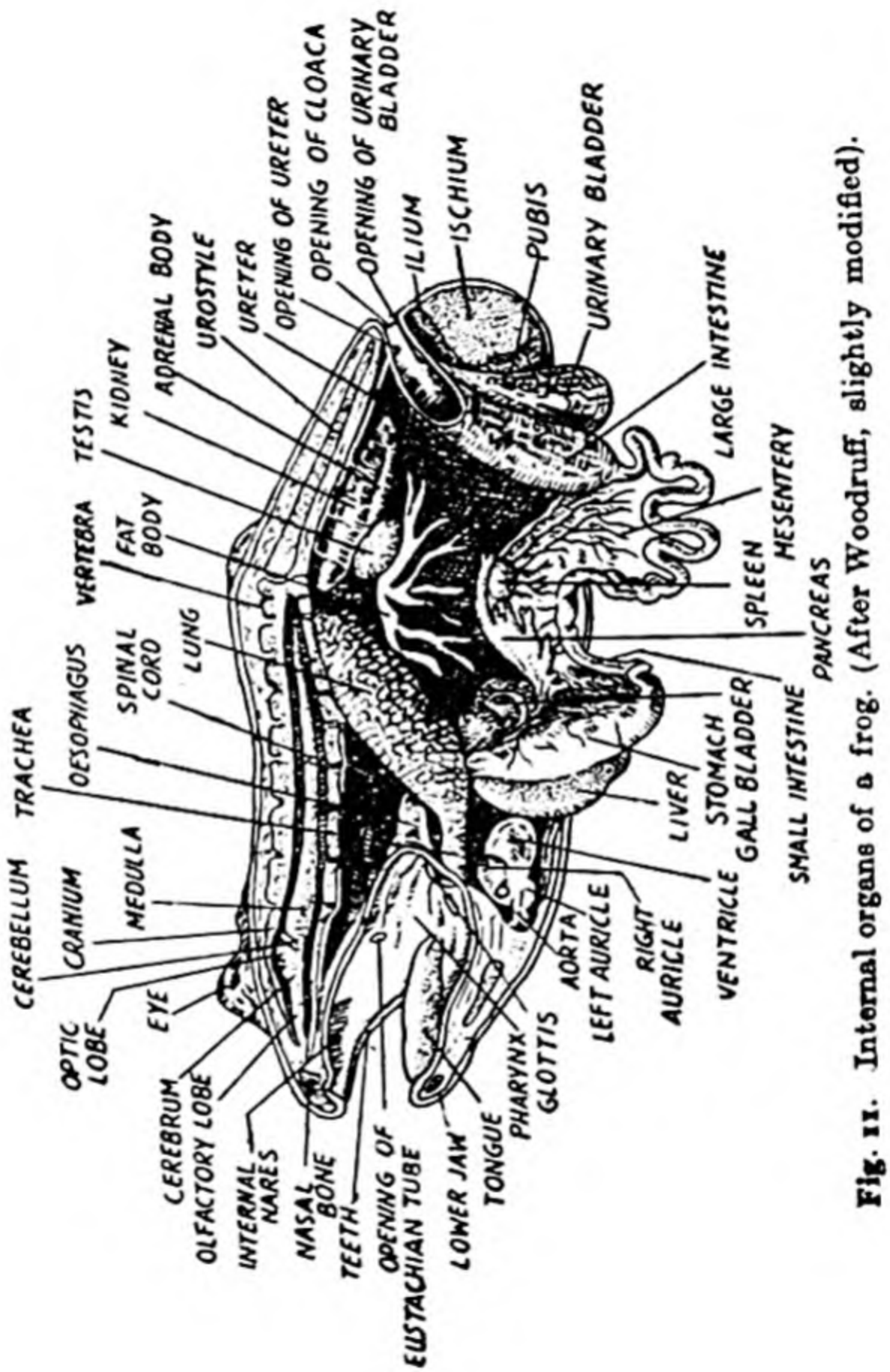

Fig. 11. Internal organs of a frog. (After Woodruff, slightly modified).

recognized, one lining the body-cavity and the other covering the viscera. The former is known as the *parietal layer* and the latter as the *visceral layer*. Although the organs are generally referred to as lying in the body-cavity, they are separated from it by the visceral layer of the peritoneum and, strictly speaking,

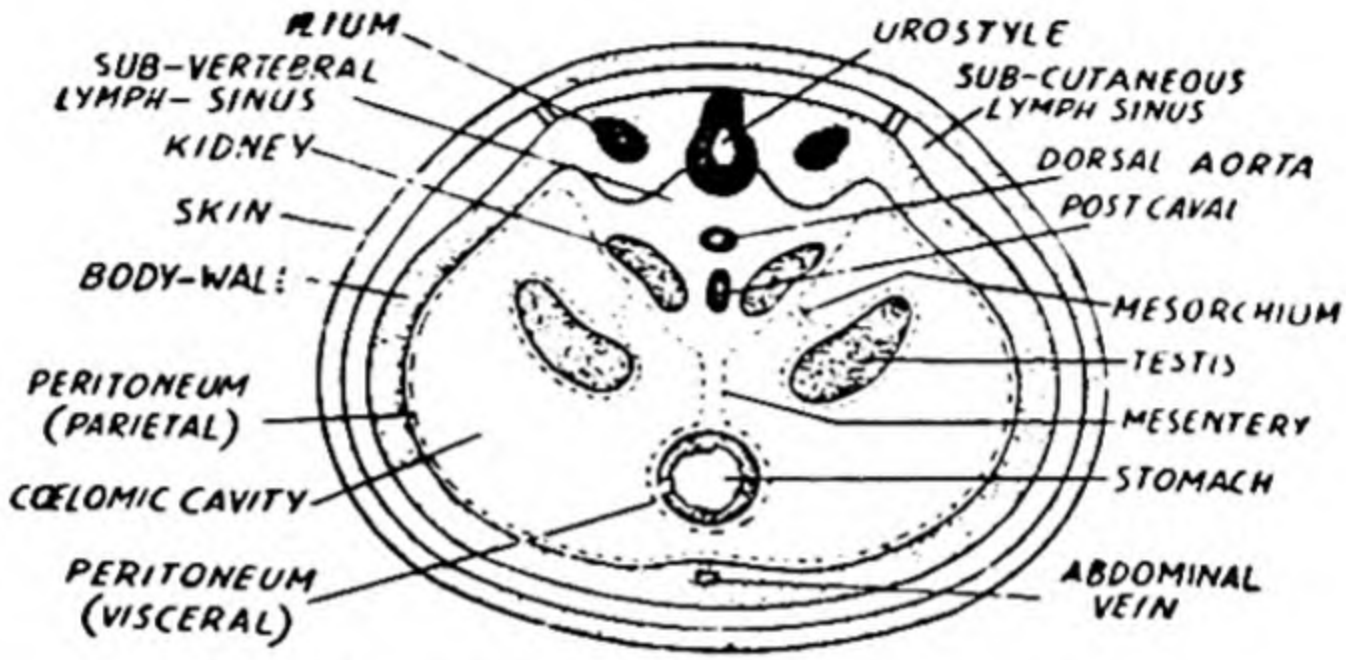

Fig. 12. Transverse section through the trunk of a frog (diagrammatic).

lie outside it The peritoneum does not line the dorsal region of the body-wall but comes down on the two sides to enclose a fairly large cavity, the *sub-vertebral lymph sinus*, filled with lymph and containing the kidneys. The latter, therefore, are covered by the peritoneum only on the ventral side. The position of the peritoneum relative to the body-cavity and the internal organs can be readily made out in a transverse section through the trunk of a frog (Fig. 12).

CHAPTER VI

THE FROG (*continued*)

THE SKELETON

The hard parts of a frog's body make up its *skeleton*. It forms a frame-work which supports the body and gives it a proper shape. It protects the more delicate parts such as the brain, heart and the sense-organs. It furnishes points of attachment for the muscles by which the animal is enabled to perform movements of different kinds. As it is internal in position, it is known as an *endoskeleton*. Skeletal structures, like the scales of a fish or the feathers of a bird, which are external in position, constitute an *exoskeleton*. In the frog there is no exoskeleton.

Ossification and Calcification. The skeleton, of the frog is composed mainly of *bone* but partly of *cartilage*, which is a tough and elastic substance harder than muscle but softer than bone. (In the tadpole the skeleton is made up entirely of cartilage, which, in the adult, is largely replaced by bone by a process known as *ossification*.) In this process bone-cells or *osteoblasts*, derived from the mesoderm, invade and grow into the cartilage. Each bone-cell retains its connection with the other cells by means of fine strands of protoplasm. Blood vessels also grow in along with the bone-cells to supply them with food and oxygen. Ultimately the cartilage is eaten up by the growing bone-cells. They now secrete, into the intercellular spaces, an organic ground-substance or *matrix*, which is heavily impregnated with calcium salts, chiefly calcium phosphate. Bone, thus, consists of a hard ground-substance impregnated with calcium salts and containing bone-cells and blood-vessels. (Ossification should be distinguished from *calcification* in which cartilage becomes calcified by the deposition of calcium salts

in its matrix. The cartilage, thus, becomes hardened but is not replaced by true bone.

Cartilage Bones and Membrane Bones. Bones which are formed in the place of pre-existing cartilage by ossification

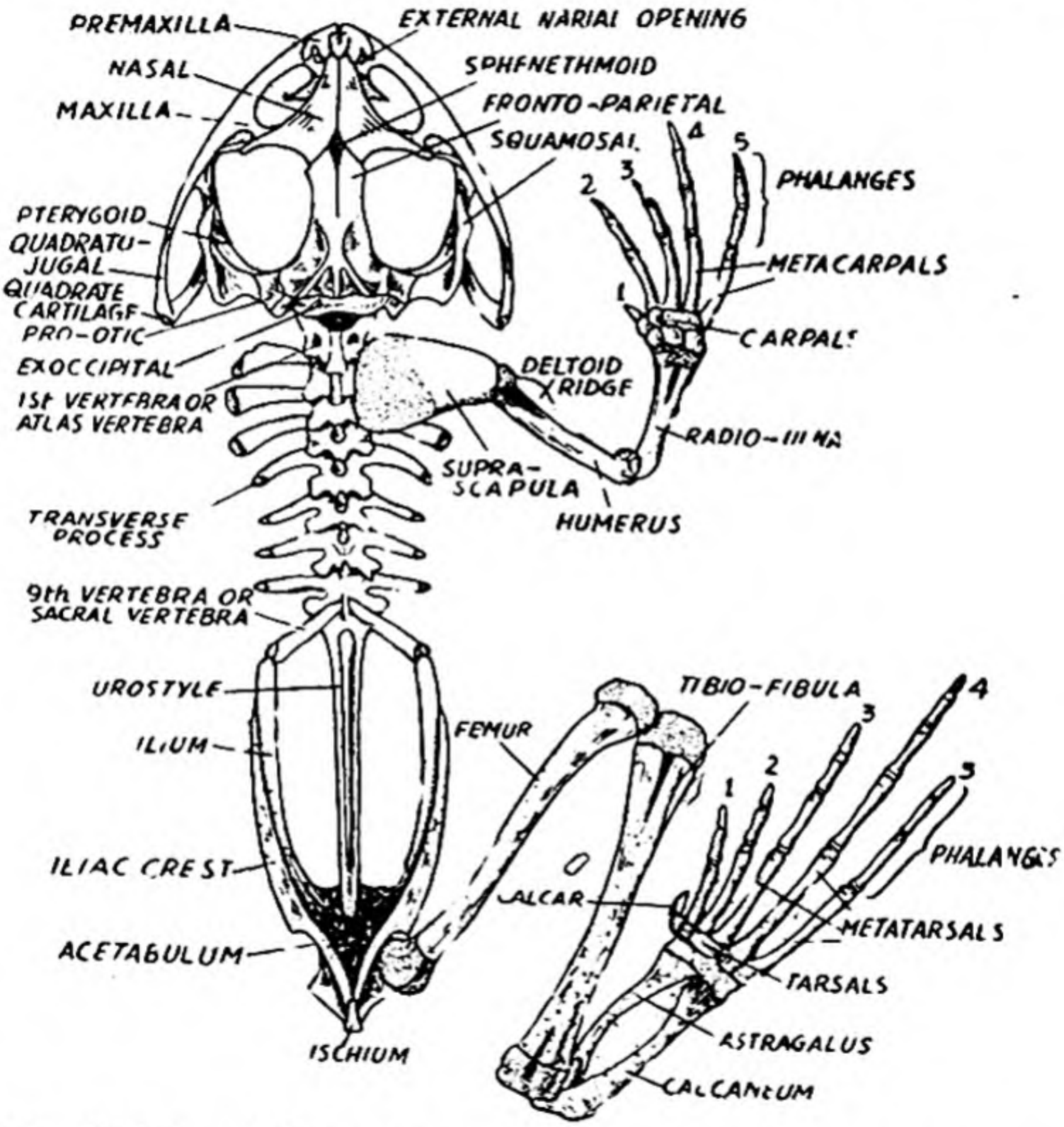

Fig. 13. Skeleton of a frog from the dorsal surface; the left half of the shoulder-girdle and the left fore and hind-limbs have been removed.

are called *cartilage bones* or *replacing bones*. Bones may also develop independently of pre-existing cartilage. Such bones are

known as *membrane bones* or *investing bones*. They arise, in the first instance, in the region of the skin by ossification of membranous connective tissue instead of cartilage. Later on they sink below the skin and become united with the underlying cartilaginous skeleton. They are, therefore, more superficially placed than cartilage bones and can be removed without much difficulty whereas the cartilage bones cannot be separated without breaking up the cartilaginous frame-work. Membrane bones are found, with rare exceptions, only in the skull while cartilage bones are found all over the body.

The skeleton of the frog may conveniently be studied under two heads : (1) the *axial skeleton*, consisting of the *vertebral column* and the *skull*, and (2) the *appendicular skeleton* including the *girdles* and the *bones of the limbs*. The *sternum*, which in reality is a part of the axial skeleton, will be considered along with the bones of the shoulder-girdle, for the sake of convenience.

AXIAL SKELETON

The Vertebral Column. The *vertebral column*, *spinal column* or the *back-bone* lies along the mid-dorsal line of the trunk. It consists of nine ring-like pieces, the *vertebrae*, and a long rod-like bone, the *urostyle*. The vertebrae are placed one behind the other and are movably united. They form a long tube which encloses and protects the spinal cord. Along the sides of the tube, between the successive vertebrae, are apertures, the *intervertebral foramina*, through which nerves from the spinal cord pass out to various parts of the body.

Structure of a Vertebra. The second to the seventh vertebrae are all more or less alike, so any one of them may be taken to study the essential structure of a vertebra. The first, eighth and ninth vertebrae possess certain peculiar features and will be considered later.

A typical vertebra (Fig. 14B) has the form of a bony ring. The central opening of the ring is the *neural canal*. The ventral

thickened portion of the ring is the *centrum* or the *body*. Its anterior face is concave and the posterior convex. This type of centrum is known as *procoelous*. The posterior convexity of each centrum fits into the anterior concavity of the centrum behind it. The articulating surfaces of the centrum are covered with a thin layer of cartilage to avoid undue friction. The circumference of the ring above the centrum forms the *neural arch*. From its top projects upwards and backwards a median process, the *neural spine*. From either side of the neural arch is given off a prominent process, the *transverse process*, which is tipped with cartilage. The neural arch bears on its anterior border a pair of flat projections, the *prezygapophyses*, facing upwards and inwards and a similar pair on the posterior border, the *postzygapophyses*, facing

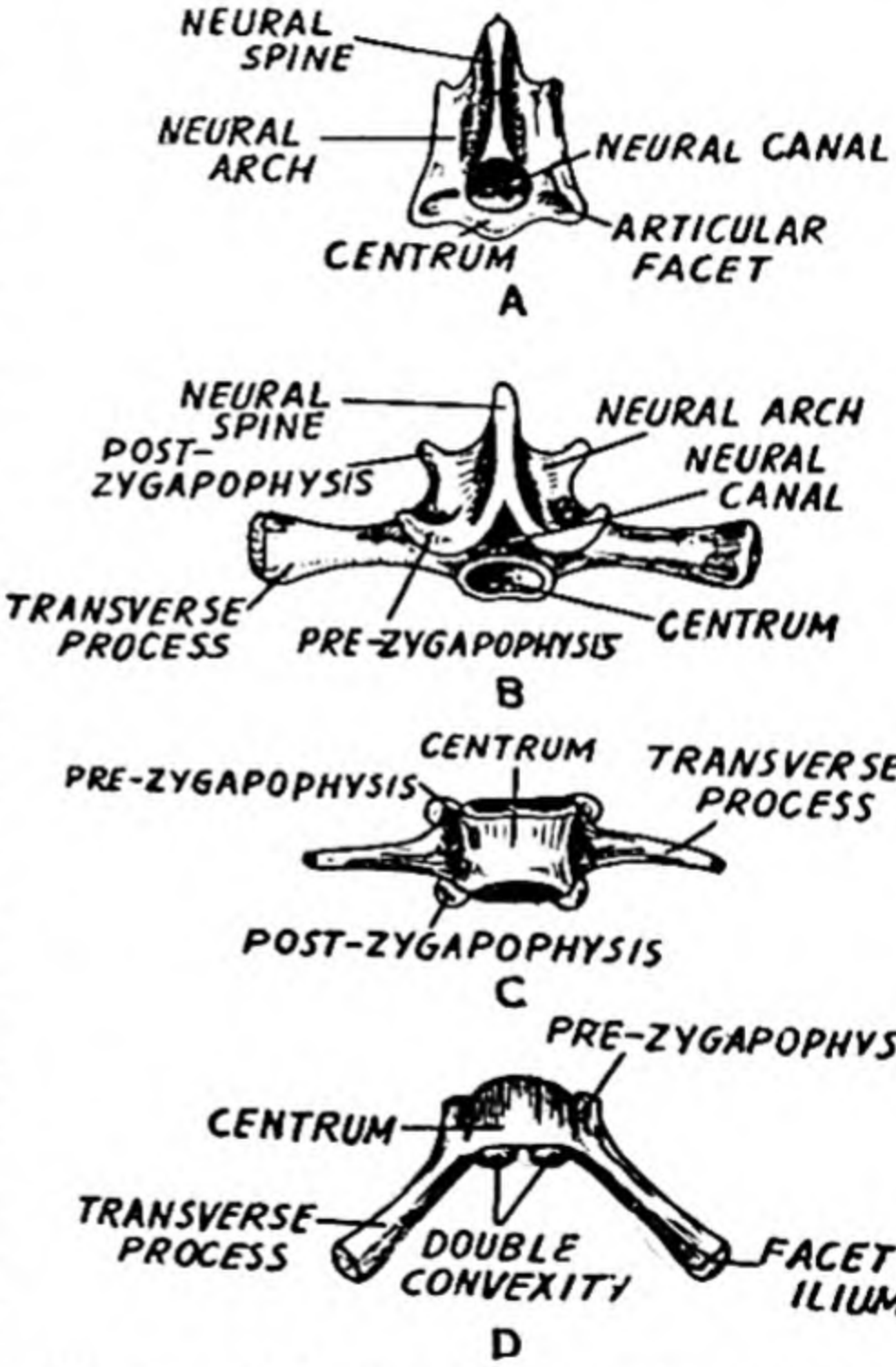

Fig. 14. Vertebrae of a frog. A, anterior view of atlas ; B, anterior view of a typical vertebra ; C, ventral view of the eighth vertebra ; D, ventral view of the ninth vertebra. (After Bhatia).

downwards and outwards. The articulating surfaces or *facets* of the zygapophyses are covered with cartilage. In the natural position the postzygapophyses of each vertebra fit above the prezygapophyses of the vertebra behind it. We have already seen that the centra of successive vertebrae also fit into one another. In this manner all the vertebrae are kept in position, at the same time they can be moved upon one another either up and down or, to a lesser degree, from side to side.

The *first* or *atlas vertebra* (Fig. 14A) has no transverse processes and the neural spine is only feebly developed. The anterior face of the centrum bears, instead of the prezygapophyses, two large concave facets for articulation with the occipital condyles of the skull. The *eighth vertebra* (Fig. 14C) can be distinguished from the rest by its centrum being concave at both ends. This type of centrum is known as *amphicoelous*. As a result of this the *ninth vertebra* (Fig. 14D) has its centrum convex in front, while behind it bears two small convex elevations which fit into two concavities at the anterior end of the urostyle. The postzygapophyses are absent. The ninth vertebra has very stout, backwardly directed transverse processes. As they support at their outer ends the hip-girdle, the ninth vertebra is designated as the *sacrum* of the *sacral vertebra*.

The *urostyle* (Fig. 15) is a long rod-like bone with a vertical tapering ridge along its dorsal surface. It represents the fused tail vertebrae of the tadpole. As already noticed, its anterior end has two concavities for articulation with the ninth vertebra. The neural canal is continued for some distance into the anterior part of the ridge and lodges the terminal portion of the spinal cord. A little behind the anterior end, on the sides, is a pair of small apertures for the exit of the tenth spinal nerves. They, therefore, correspond to the intervertebral fora-

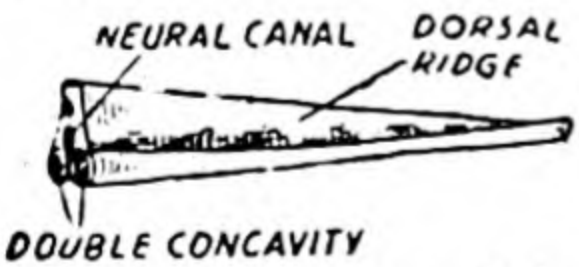

Fig 15.—Antero-lateral view of the urostyle of a frog.

mina. These apertures are sometimes absent either on one or both sides.

The Skull. The *skull* (Figs. 13 and 16—19) forms the skeleton of the head. It is composed of both cartilage and bone. In the tadpole the skull like the rest of the skeleton, is made up entirely of cartilage. This cartilaginous foundation of the skull is known as the *chondrocranium* (Fig 16). Its roof has a large opening, the *fontenelle*. There is in front a pair of olfactory capsules while at the hinder end is a pair of auditory capsules. The Meckel's cartilage, which forms the skeleton of

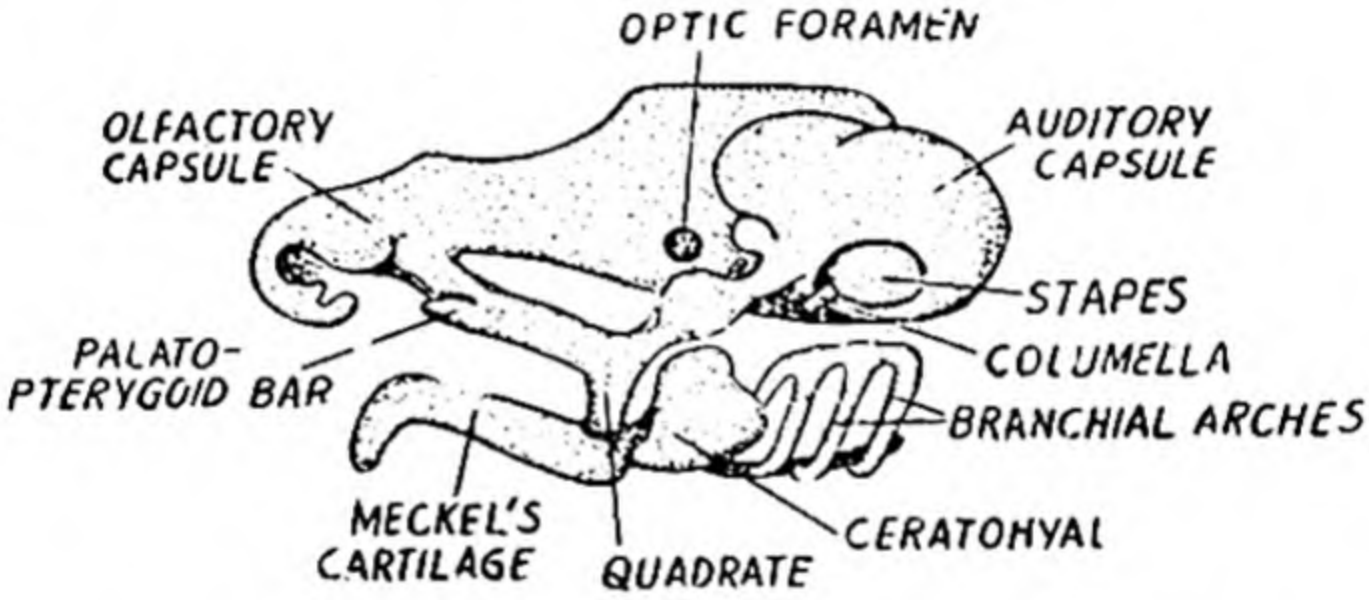

Fig 16. Chondrocranium of the tadpole, lateral view. (After Marshall).

the lower jaw. is suspended from the skull by the quadrate. This is known as the *suspensorium*. Below the cranium, on either side, is a series of four *branchial arches* which support the gills. In front of the branchial arches is the *hyoid arch* of which the *ceratohyal* is a part. When the gills disappear and the gill-slits are closed the hyoid and the branchial arches become reduced to form the columella and the hyoid apparatus of the adult. During development a considerable part of the chondrocranium becomes ossified into cartilage bones. At the same time a large number of membrane bones are developed

which cover the chondrocranium practically on all sides and become firmly united with it.

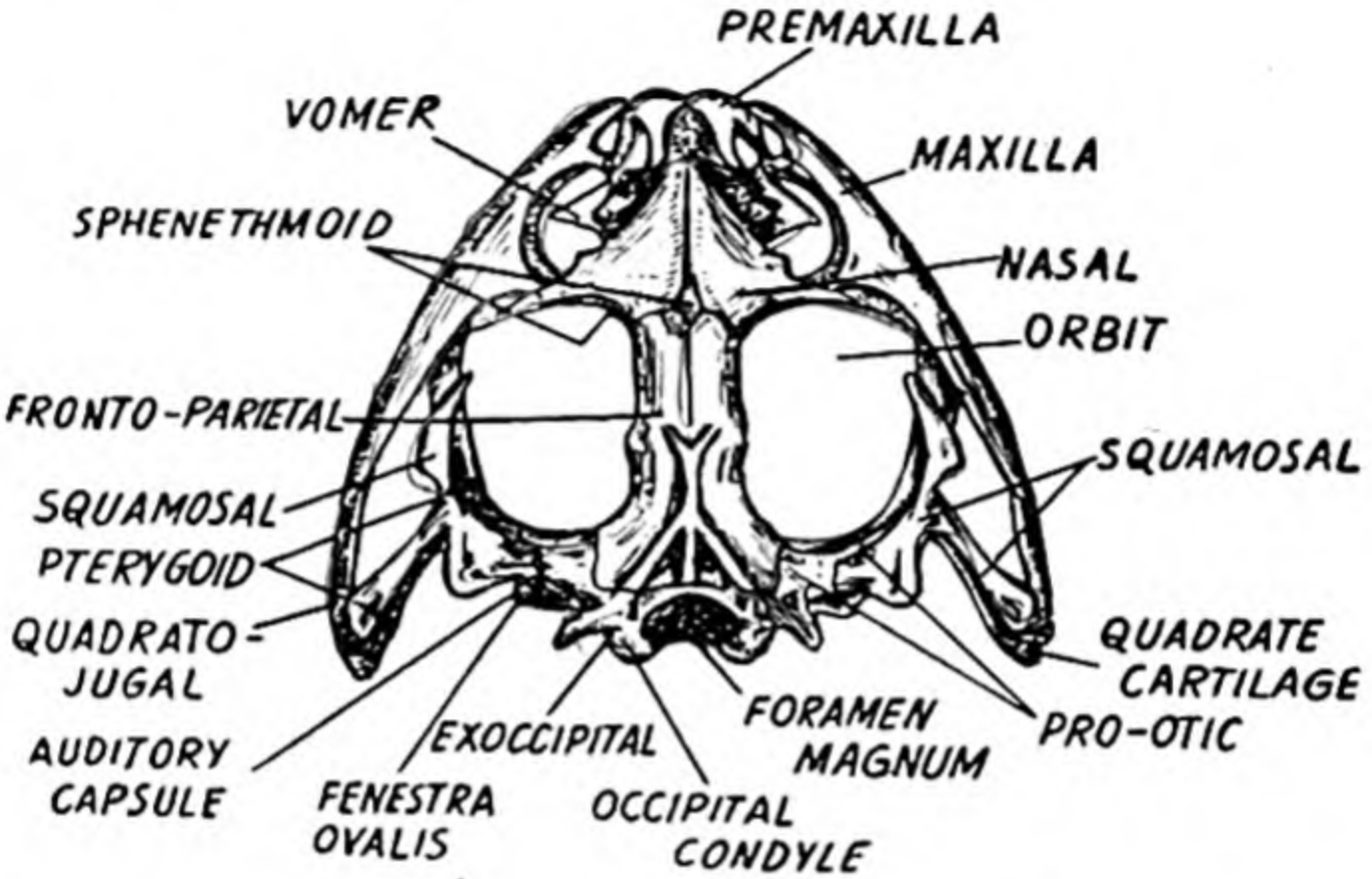

Fig. 17. Skull of a frog. A, dorsal view ; B, ventral view.

The skull may be divided into six regions, namely, the *cranium*, the *auditory* and *olfactory capsules*, the *upper* and *lower jaws* and the *hyoid apparatus*.

The Cranium. The *cranium* or the *brain-case* occupies the middle portion of the skull in continuation with the vertebral column. It is a hollow structure, roughly cylindrical in shape, and lodges the brain. It is pierced by a number of apertures of *foramina* for the cerebral nerves to pass out from the brain. On either side of the cranium is a large gap, the *orbit*, in which the eye is contained.

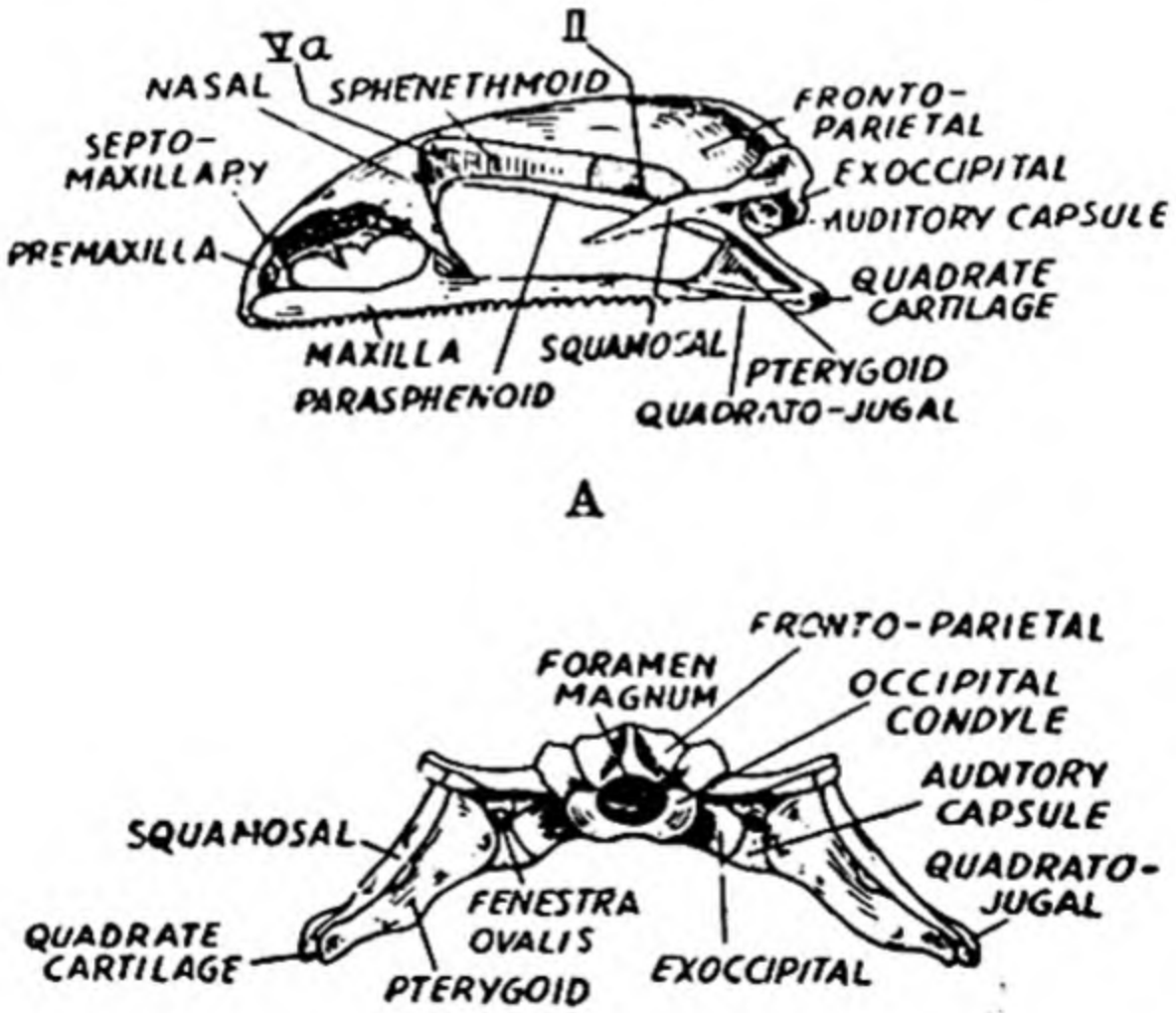

Fig. 18.—Skull of a frog. A, lateral view ; B, posterior view.

The posterior wall of the cranium is formed by a pair of irregular bones, the *exoccipitals*. They surround a large opening, the *foramen magnum*, through which the spinal cord emerges

from the brain. They bear a pair of oval projections or knobs, the *occipital condyles*, by means of which the skull articulates with the atlas vertebra. The *fronto-parietals* are two long flat bones lying side by side and forming the roof of the cranium. They cover the fontenelle in the roof of the chondrocranium In the young frog each fronto-parietal consists of two distinct bones, an anterior *frontal* and a posterior *parietal*, which fuse completely during the growth of the animal. Covering the ventral surface of the cranium is a large T shaped bone, the *parasphenoid*. Its long arm is directed forwards while the cross-piece extends outwards beneath the *auditory capsules*. In front of the cranium and partly overlapped by the fronto-parietals and nasals above and the parasphenoid below is a tubular bone, the *sphenethmoid*. From the dorsal side only a small diamond-shaped area of the bone is visible between the fronto-parietals and the nasals. The sphenethmoid, as its name implies, consists of two regions, a posterior *sphenoidal* and an anterior *ethmoidal*. The two regions are separated by a transverse partition which forms the anterior wall of the cranial cavity. The sphenoidal region, thus, lodges the front end of the brain. The ethmoidal region is further divided by a vertical wall into right and left compartments which enclose the posterior parts of the *olfactory sacs* or the organs of smell. In the cranium the exoccipitals and sphenethmoid are cartilage bones while the fronto-parietals and parasphenoid are membrane bones.

It has already been mentioned that the cranium is pierced by a number of foramina for the exit of the cerebral nerves which arise from the brain. There are ten pairs of cerebral nerves in the frog. The *first nerve* passes out through a foramen in the transverse partition of the sphenethmoid. It is not visible in the entire skull The *second nerve* makes its exit through a large aperture, the *optic foramen*, in the side-wall of the cranium just behind the sphenethmoid. The *third* and *fourth nerves* have their foramina behind the optic foramen, that

for the fourth being larger than and lying above that for the third. The *fifth, sixth* and *seventh nerves* leave the skull by a large common aperture in the pro-otic bone on the ventral side. The *eighth nerve* passes through a foramen, not seen in the complete skull, in the inner wall of the auditory capsule. The *ninth* and *tenth nerves* leave the skull together by an aperture in the exoccipital on the outer side of the occipital condyle.

The Auditory Capsules. The *auditory capsules* are a pair of projections on the sides of the posterior end of the cranium, lying above the cross-piece of the parasphenoid. They lodge and protect the essential organs of hearing. They are composed of both cartilage and bone. A large part of each capsule is ossified to form a saddle-shaped bone, the *pro-otic*, the rest of it remaining cartilaginous throughout life. The cartilage, however, is hardened by calcification. The pro-otic not only forms the roof and the anterior wall of the capsule but takes a share in bounding the posterior face of the orbit. In the outer wall of the capsule is an aperture, the *fenestra ovalis*, into which is inserted, through the intermediation of the *stapes*, the inner end of a small rod of bone, the *columella*, while its outer end is applied to the inner surface of the tympanic membrane.

The Olfactory Capsules. The *olfactory capsules* are a pair of irregular masses united with the anterior end of the cranium, and also with each other in the middle line. They lodge the organs of smell. They consist largely of cartilage but are strengthened by two paired membrane bones. The dorsal surface of the capsules is covered by a pair of large triangular bones, the *nasals*. They meet each other in the middle line in front but their posterior ends diverge and meet the anterior ends of the fronto-parietals thus exposing a diamond-shaped area of the sphenethmoid. Corresponding to the nasals above there is a pair of smaller tri-radiate bones, the *vomers*, supporting the capsules from below. The two vomers are approximated behind but diverge anteriorly. The posterior border of each bears the *vomerine teeth*.

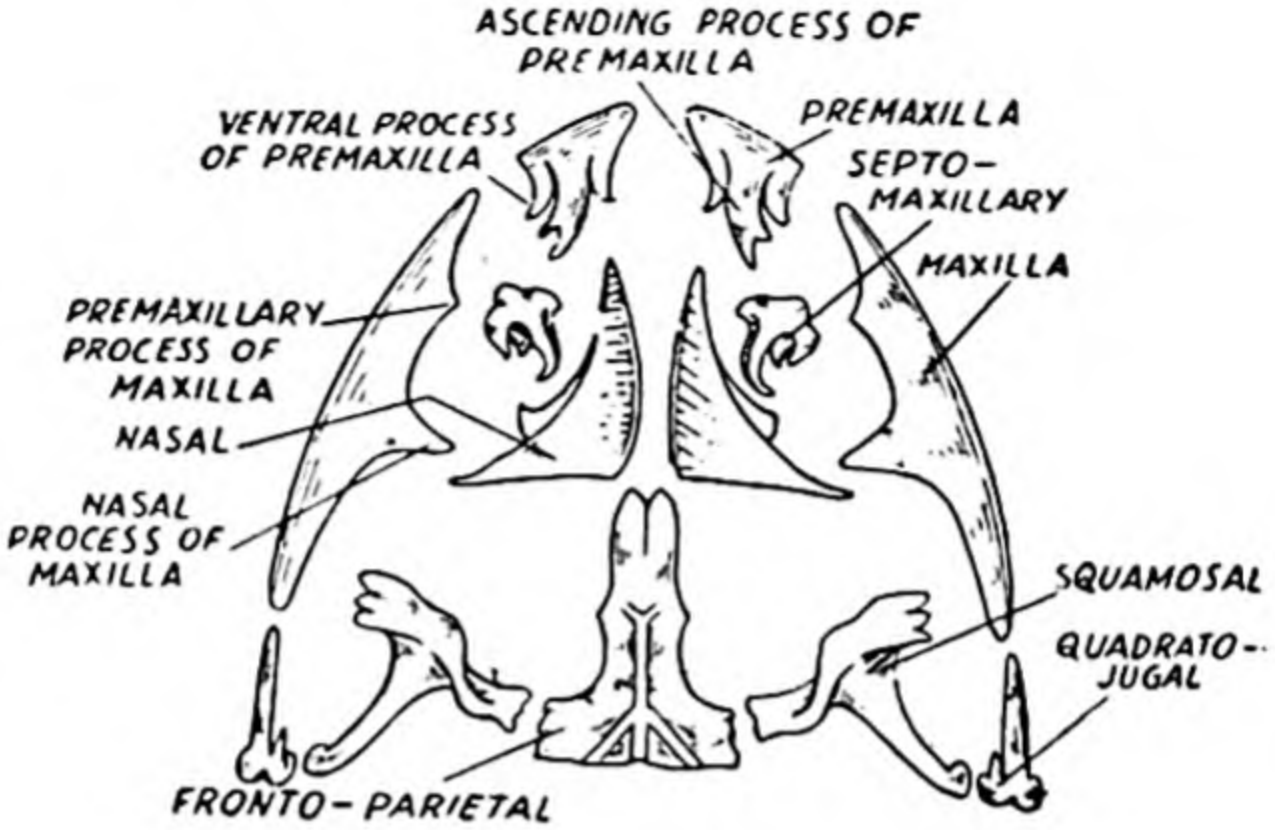

Fig. 19. Disarticulated membrane bones of the skull of a frog. A, dorsal side ; B, ventral side. (After Bhatia).

The Upper Jaw. The *upper jaw* is semi-oval in outline and forms the outer border of the skull. It is immovably united with the olfactory capsules in front and the auditory capsules behind. It consists of two halves which meet in the middle line in front. Each half of the upper jaw consists of two sets of bones, an outer and an inner. The outer set includes three membrane bones lying one behind the other and supporting on their own side the upper border of the mouth. In front is a small bone, the *premaxilla*, which meets its fellow in the middle line. (It gives off from its dorsal surface a backwardly directed process.) The premaxilla bears teeth along its lower edge. It is followed by a long, thin, curved bone, the *maxilla*, which forms the major part of the upper jaw. It also is provided with teeth. (Posteriorly the maxilla is united, by an oblique contact, with a delicate and slender bone, the *quadrato-jugal*, which has no teeth.) Of the bones of the inner set, which are all membrane bones, the *palatine* is a transverse rod-like bone connecting the maxilla with the sphenethmoid and, thus, forming the anterior edge of the orbit on the ventral side. The *pterygoid* is a large tri-radiate bone on the ventral side of the skull. Its outer limb is connected with the maxilla and the inner limb with the auditory capsule, the two together forming the outer rim of the orbit on the ventral side. The posterior limb extends backwards and outwards to the angle of the jaw. The *squamosal*, which is best seen in a lateral view of the skull, is a T-shaped bone. It lies at the side of the auditory capsule. The main stem runs backwards to the angle of the jaw dorsal to the posterior limb of the pterygoid. The cross-piece forms a part of the posterior edge of the orbit on the dorsal side. The *quadrate* is a rod of cartilage which is connected below with the posterior end of the quadrato-jugal and extends inwards and forwards to unite with the auditory capsule above. It lies between the long arm of the squamos

and the posterior limb of the pterygoid and is visible only where it peeps out between these two bones. The quadrate cartilage, along with the long limb of the squamosal and the posterior process of the pterygoid, serves to suspend the lower jaw from the skull. The three together, therefore, constitute what is known as the *suspensorium*.

The Lower Jaw. The *lower jaw* or *mandible* (Fig. 20), like the upper jaw, is semi-oval in outline. It supports the lower border of the mouth, and articulates posteriorly with the skull through the suspensorium. It is made up of two halves or *rami*.

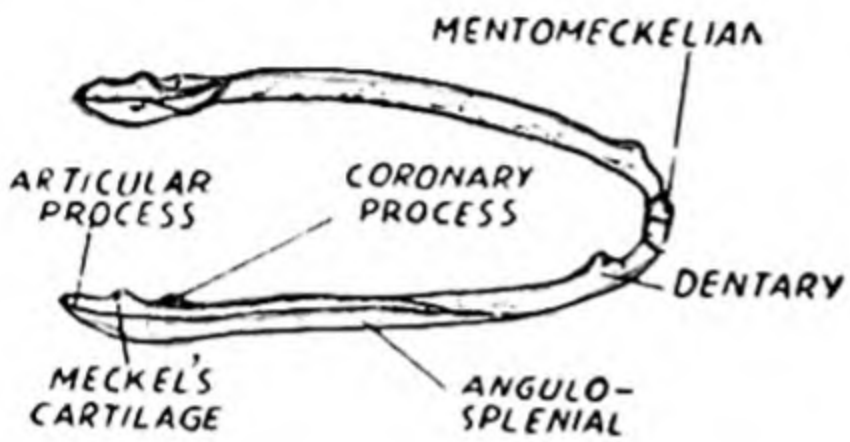

Fig. 20. The lower jaw of a frog.

Each *ramus* is a curved bar united with its fellow in front by ligament. In the tadpole the ramus is made up of a rod of cartilage, the *Meckel's cartilage*, which in the adult is strengthened by cartilage bones and membrane bones. At its anterior end is a small bone, the *mentomeckelian*, formed by the ossification of the cartilage itself. In addition there are two membrane bones which cover practically the whole of the Meckel's cartilage The *dentary* is a flat bone lying on the outer surface of the anterior half of the Meckel's cartilage just behind the mentomeckelian. The *angulo-splenial* covers the inner surface, the lower edge and partly the outer surface of the Meckel's cartilage. It is connected with the dentary by an oblique union. At the hinder end on the upper surface each ramus bears a facet for articulation with the skull In front of the facet is a projection of the angulo-splenial known as the *coronary process*.

The Hyoid Apparatus. The *hyoid apparatus* (Fig. 21) is a thin shield-shaped plate of cartilage produced in front

and behind into slender paired processes. It is the remnant of the gill-arches which support the gills of the tadpole It lies in the floor of the mouth beneath the tongue. Its central shield-shaped plate is known as the *body of the hyoid* and processes as *horns* or *cornua*. The antero-lateral and the postero-lateral angles of the body of the hyoid are produced into the *alar* and *posterior lateral processes* respectively. The *anterior cornua* are a pair of long slender processes which curve backwards and then upwards round the angle of the mouth to finally join with the auditory capsules. The *posterior cornua* are a pair of short diverging bony processes arising from the posterior border of the body of the hyoid. They lie one on either side of the glottis. All parts of the hyoid apparatus, except the posterior horns, are cartilaginous.

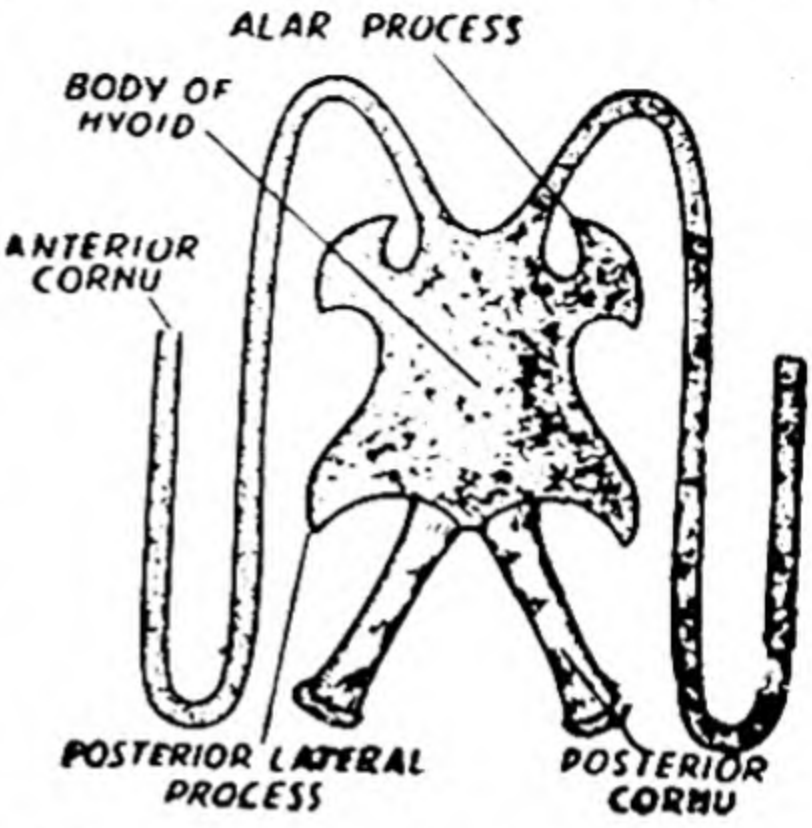

Fig. 21. The hyoid apparatus of a frog.

We have seen that the skull of an adult frog contains, in addition to some parts of the original cartilaginous frame-work, a number of cartilage bones and membrane bones. These two types of bones in the frog's skull have been tabulated below :—

Region	*Replacing or Cartilage Bones*	*Investing or Membrane Bones*
Cranium	Exoccipitals Sphenethmoid (posterior part)	Fronto-parietals Parasphenoid

Region	*Replacing or Cartilage Bones*	*Investing or Membrane Bones*
Olfactory Capsule	Sphenethmoid (anterior part)	Nasals Vomers
Auditory Capsule	Pro-otics	
Upper Jaw		Premaxillæ Maxillæ Quadrato-jugals Palatines Pterygoids Squamosals
Lower Jaw	Mentomeckelians	Dentaries Angulo-splenials
Hyoid	Posterior Cornua Columellæ	

APPENDICULAR SKELETON

The *appendicular skeleton* consists of the *pectoral* and *pelvic girdles* and bones of the *fore* and *hind-limbs*. Like the axial skeleton it consists, in the tadpole, entirely of cartilage which is replaced in the adult, to a large extent, by cartilage bones. Membrane bones are absent, a notable exception being the *clavicles* in the pectoral girdle.

The Pectoral Girdle. The *pectoral* or *shoulder-girdle* (Fig. 22) encircles the anterior region of the trunk and provides a base for the attachment of the fore-limbs. The girdle, along with the sternum protects the heart and the lungs. It is made up of two similar halves which are united with each other in the mid-ventral line. The union is known as a *symphysis*. Dorsally the two halves are free from each other but are attached by ligaments and muscles to the vertebral column. Each half may be divided into a dorsal *scapular* and a ventral *coracoid portion*. The *scapular portion* consists of an under

broad *supra-scapula* and a lower narrow *scapula*. The supra scapula is a flat plate of cartilage impregnated with calcium

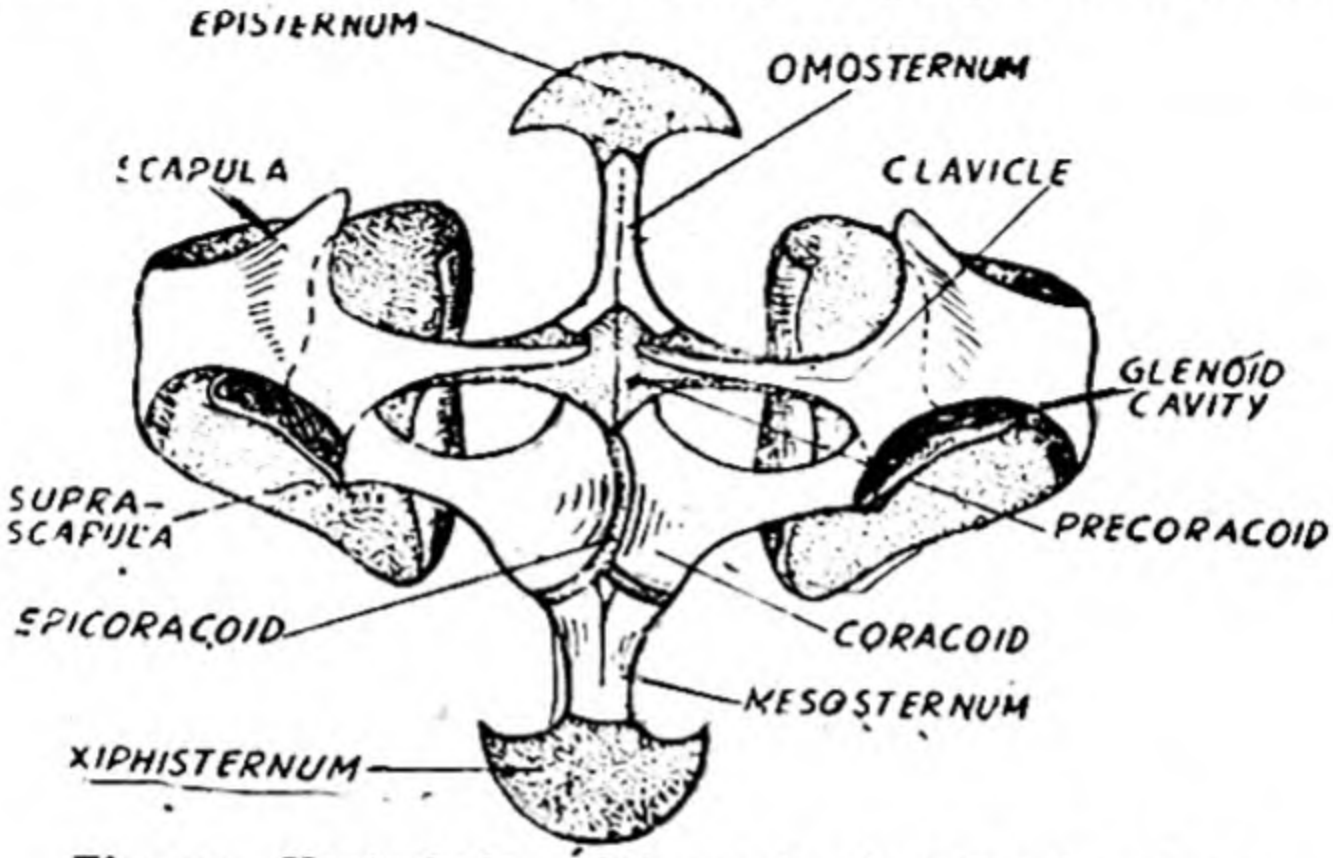

Fig. 22. Ventral view of the pectoral girdle of a frog.

salts except along the upper free margin which consists of plain cartilage. The lower part of the supra-scapula, adjoining the scapula, is covered dorsally by a thin sheet of bone. The *coracoid portion* contains a large semi-circular opening, the *coracoid foramen*, which is bounded in front by a transverse rod of calcified cartilage, the *pre-coracoid* and behind by a stout *coracoid*. Between the pre-coracoids and coracoids of the two sides and applied to each other in the mid-ventral line are two narrow strips of cartilage, the *epi-coracoids*. As in *Rana tigrina* the inner ends of the coracoids, which are tipped with cartilage, overlap each other, the epi-coracoids are not distinctly visible. The pre-coracoid is covered along its antero-dorsal border by the only membrane bone of the gridle, the *clavicle*. At the junction of the scapula and coracoid, on either side, is a cup-shaped depression, the *glenoid cavity*, for articulation with the bone of the upper arm.

The *sternum* (Fig. 22) consists of two bones, tipped with

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cartilage, in line with the epi-coracoids. The bone in front, which is forked at the base, is the *omosternum* and its cartilaginous terminal piece the *episternum*. The bone behind is the *mesosternum* and its broad cartilaginous tip the *xiphisternum*.

The Fore-limb. The *upper arm* is supported by a single bone, the *humerus*. Its proximal end or *head*, which is com-

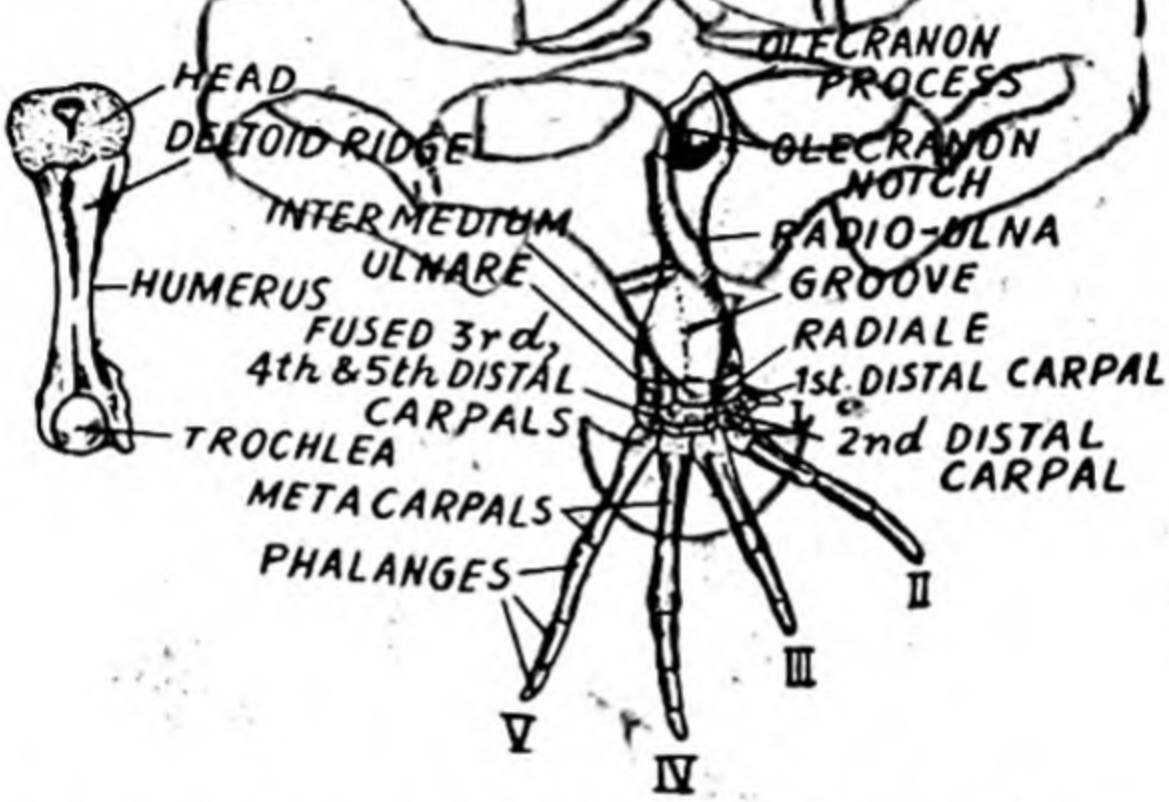

Fig. 23. Skeleton of the right fore-limb of a frog.

posed of partially calcified cartilage, fits into the glenoid cavity of the pectoral girdle. Its distal end, the *trochlea*, which is made up of spongy bone, articulates with the bone of the fore-arm. The main part of the bone or *shaft* is marked by a prominent *deltoid-ridge* running along its proximal half on the anterior side.

In the *fore-arm* there are two bones fused together constituting the *radio-ulna*. Its proximal end bears a depression the *olecranon notch*, for articulation with the humerus to form the elbow-joint behind which it is produced into a small *olecranon process*. Its distal end articulates with the *wrist bones* or *carpus* by a double facet. In the tadpole the fore-arm contains two distinct cartilages, the *radius* on the pre-axial or inner side.

and the *ulna* on the post-axial or outer side. During the course of development the two components fuse together but their fusion is marked by a groove which clearly shows the double nature of the bone. Further proof of this is afforded by a transverse section of the bone in the region of the groove which reveals two distinct narrow cavities inside it.

The *wrist* consists of six *carpal bones* arranged in two rows of three each. The bones of the proximal row, which articulate with the radio-ulna, are called, according to their position, the *radiale*, *intermedium* and *ulnare*. The distal row is attached to the bones of the palm or *metacarpals*. In the early stages of development it consists of five distinct bones, corresponding to the five digits but later on the third, fourth and fifth of these become fused into one. The *centrale*, which is normally found between the two rows of carpals, is also fused with them. The fusion of these bones gives strength to the wrist which has to bear the weight of the body when the frog falls on the ground after a leap. There are five *metacarpals* but the first one is very small. The bones of the fingers or *digits* are known as *phalanges*. The proximal phalanx of each digit articulates with the corresponding metacarpal. Although the thumb or first digit is absent in the frog it is represented by a small phalanx which remains hidden under the skin. So the four visible digits in the frog's hand are the second, third, fourth and fifth, which contain two, two, three and three phalanges respectively.

The Pelvic Girdle. The *pelvic* or *hip-girdle* (Fig. 24) lies in the posterior region of the trunk and supports the hind-limbs. The girdle consists of two similar halves which diverge anteriorly but are fused behind in the median plane to form a vertical disc. On either face of the disc is a cup-shaped cavity, the *acetabulum*, into which the head of the thigh-bone fits to form the hip-joint. Each half of the girdle consists of three bones, the boundaries of which are marked on the disc by

two lines or sutures passing through the acetabulum. All the three bones, thus, take part in the formation of the acetabulum.

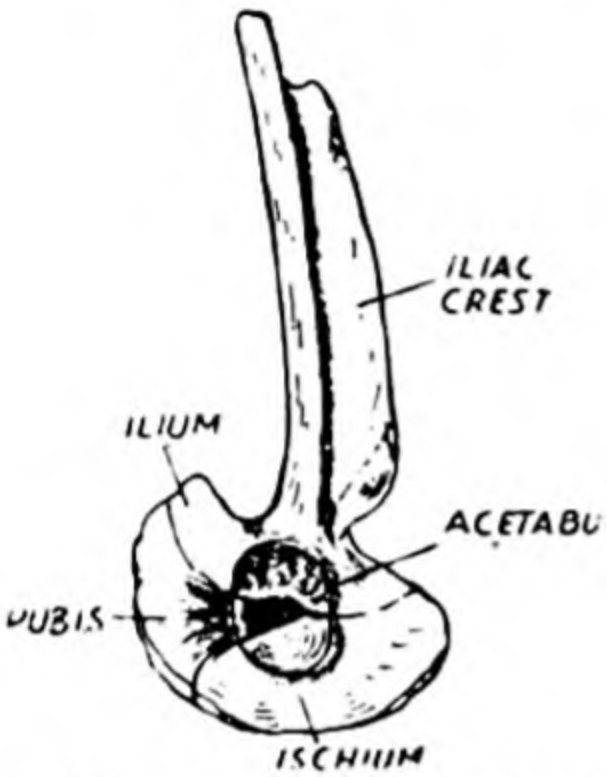

Fig. 24. Lateral view of the pelvic girdle of a frog.

Its anvero-dorsal half is formed by the *ilium* which extends forwards to articulate by its distal end with the transverse, process of the ninth vertebra. The arm of the ilium bears along its upper edge a vertical ridge, the *iliac crest*. Posteriorly the two ilia are united together in the median plane. The remaining half of the acetabulum is shared by the *ischium*, which forms the posterior portion of the disc, and the *pubis* which lies on its ventral side. Both the ilium and the ischium are replacing bones while the pubis is composed of calcified cartilage. In the early stages of development they become united in the median plane to form a *symphysis*, only the arms of the ilia remaining separate.

The Hind-limb. The bones of the *hind-limb* (Fig. 25) correspond to those of the fore-limb, but are longer and stouter. The thigh contains a single bone, the *femur*, which has a slightly curved shaft and rounded extremities, composed of clacified cartilage. The proximal end or the *head* articulates with the acetabulum while the distal end, the *condyle*, which is somewhat broader, articulates with the shank-bone or *tibio-fibula*. This is a little longer than the femur and is expanded towards the ends. Like the radio-ulma it is formed by the fusion of two bones, the *tibia* and the *fibula*. This is evident from the presence of a central groove between the two components and two marrow cavities inside them.

The *ankle* consists of four *tarsal bones* arranged in two rows

of two each. The tarsals of the proximal row, known as *tibiale* or *astragalus*, and *fibulare* or *calcaneum*, are greatly elongated

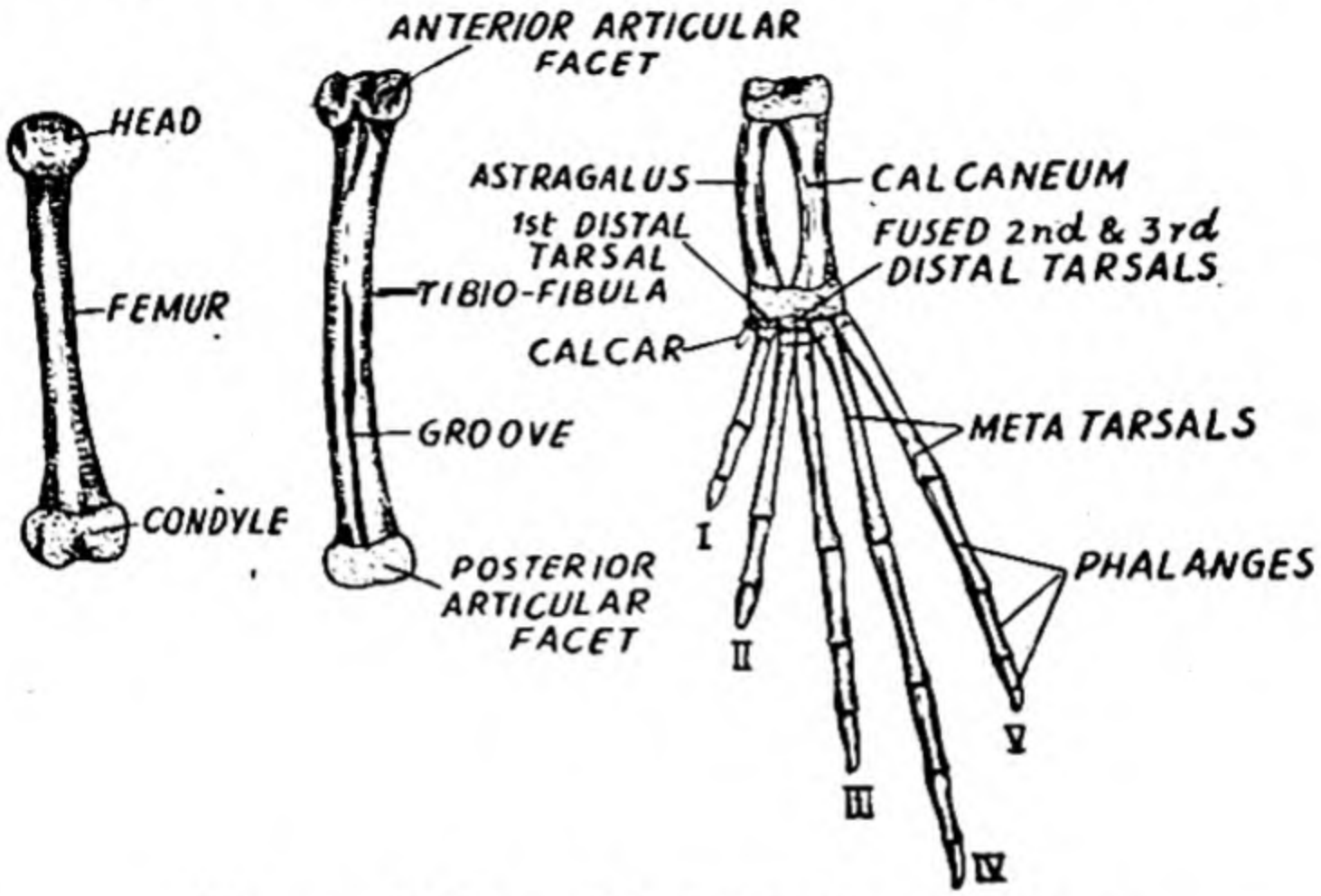

Fig. 25. Skeleton of the left hind-limb of a frog.

and united together at the two ends, by common epiphyses, with a gap in the middle. The astragalus is on the pre-axial or tibial side and the calcaneum on the post-axial or fibular side. They add to the length of the limb and thus increase the leaping power of the frog. The tarsals of the distal row are very small. The inner one is the first distal tarsal and the outer one represents the fused second and third distal tarsals, the fourth and fifth being absent. There are five *metatarsals* in the foot corresponding to metacarpals in the hand. There are five *toes* or digits articulating with the metatarsals. The first and second digits bear two phalanges each, the third and fifth, three each, and the fourth, four. On the inner side of the distal row of tarsals is a small conical process, the *calcar*, consisting of a short metatarsal and one or two phalanges. It should be considered as an additional toe.

CHAPTER VII

THE FROG (*continued*)

JOINTS AND MUSCLES

Joints. When two or more bones are fitted together they make a *joint*. The joints are of these types : *perfect*, *imperfect* and *immovable*.

A *perfect joint* permits free movement at the point of the union between the bones. The hip-joint (Fig. 26) may be taken as an example of a perfect joint. We have already seen that the hip-girdle has, on either side, a cup-shaped depression, the acetabulum, into which the ball-shaped head of the femur fits nicely. To ensure smooth working of the joint both the acetabulum and the head of the femur are covered with a thin layer of cartilage. A strong sheet of connective tissue, having the form of a tube, unites the femur with the girdle. The proximal end of the tube is attached to the girdle around the rim of the acetabulum while its distal end is fixed around the femur just below its head. Such sheets or bands of connective tissue which bind the bones together are known as *ligaments*. The ligament of the hip-joint is called a *capsular ligament*. From the fore-going account it is clear that the head of the femur is completely covered, partly by the ligament and partly by the acetabulum. A space, however, is

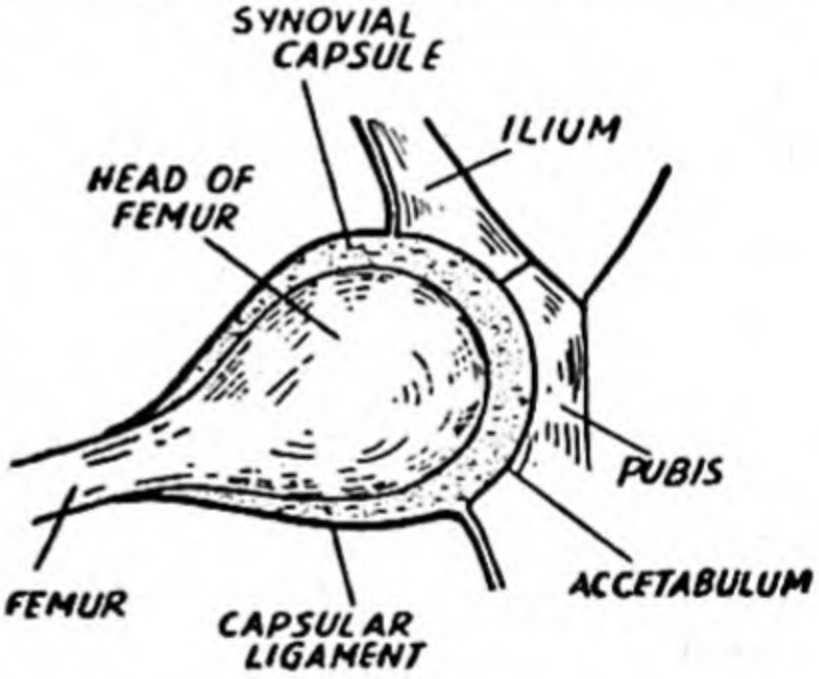

Fig. 26. Horizontal section of a frog's hip-joint (diagrammatic).

left all round between the head of the femur on the inside and the ligament and the acetabulum on the outside. This space is known as the *synovial capsule*. It is filled with a watery fluid, the *synovia*, which acts as a cushion between the bones forming the joint. The synovia, thus, protects the bones from friction and the capsular ligament binds them together and prevents their dislocation. A joint, like the hip-joint, in which the rounded head of one bone fits into a cup or socket in another, is called a *ball and socket joint*. This type of joint allows movement in all directions including rotation.

The shoulder-joint provides another example of the ball and socket type. The ball is furnished by the head of the humerus and the socket by the glenoid cavity. A shallow type of ball and socket joint is formed by the centra of any two successive vertebrae. The posterior convex surface of one centrum fits into the anterior concave surface of the one behind.

Other types of perfect joints found in the frog are the *hinge-joint* and the *gliding joint*. Both these types have the same general plan as the ball and socket joints, that is, the bones are covered with cartilage, separated by a synovial capsule and bound together by ligaments. In the *hinge-joint*, common examples of which are the elbow and the knee joints, the shape of the bones and the manner of attachment of the ligaments permit movement only in an up and down direction. The joint between the lower jaw and the skull also belongs to this type. An example of a *gliding joint* is furnished by the zygapophyses of the vertebrae which glide on each other either up and down or from side to side, though only to a limited extent.

In an *imperfect joint* the bones are united by an intervening layer of cartilage which, being flexible, permits them a slight movement. There is no synovial capsule. The joints between the bones of the shoulder-girdle or the hip-girdle belong to this category.

An *immovable joint*, as the name implies, permits no movement at all. It is also known as a *suture*. The bones, in this case, are directly and firmly united with one another without the intervention of any other material. The joints betweent he bones of the skull are of this type.

Muscles. We have already learnt that the body of an animal is made up of various kinds of tissues. One of them is the *muscular tissue*. It is mainly concerned with the production of various kinds of movements. The muscular tissue consists of fine threads or *fibres* arranged in bundles which are bound together by connective tissue to form *muscles*. Their chief property is that they can contract to a considerable extent. It is due to this property of the muscular tissue that an animal is able to perform movements.

Voluntary and Involuntary Muscles. Muscles may be *voluntary* or *involuntary*. *Voluntary muscles* are those which are under the control of the will such as the limb-muscles. The frog may leap or swim whenever it desires to do so. The *involuntary muscles*, on the other hand, are not governed by the will of the animal. They work automatically without any effort, or even knowledge, of the animal concerned. Examples of involuntary muscles are those of the heart and the intestine.

Voluntary Movements. Let us now see how a voluntary movement is performed by the frog. As stated above, a muscle is capable of contraction to a considerable degree. When it contracts it decreases in length but increases in thickness. Experiments have shown that contraction of a muscle takes place when a mechanical, chemical, thermal or an electrical stimulus is applied to it. In the natural life of the frog it is very seldom that any of these stimuli directly reaches the muscles. The stimulus, therefore, comes to the muscles from the animal itself. In this process another system, the nervous system, is involved. This system consists mainly of the brain,

spinal cord and nerves. It works, more or less, like a telegraph system. The brain may be compared to the telegraph office,

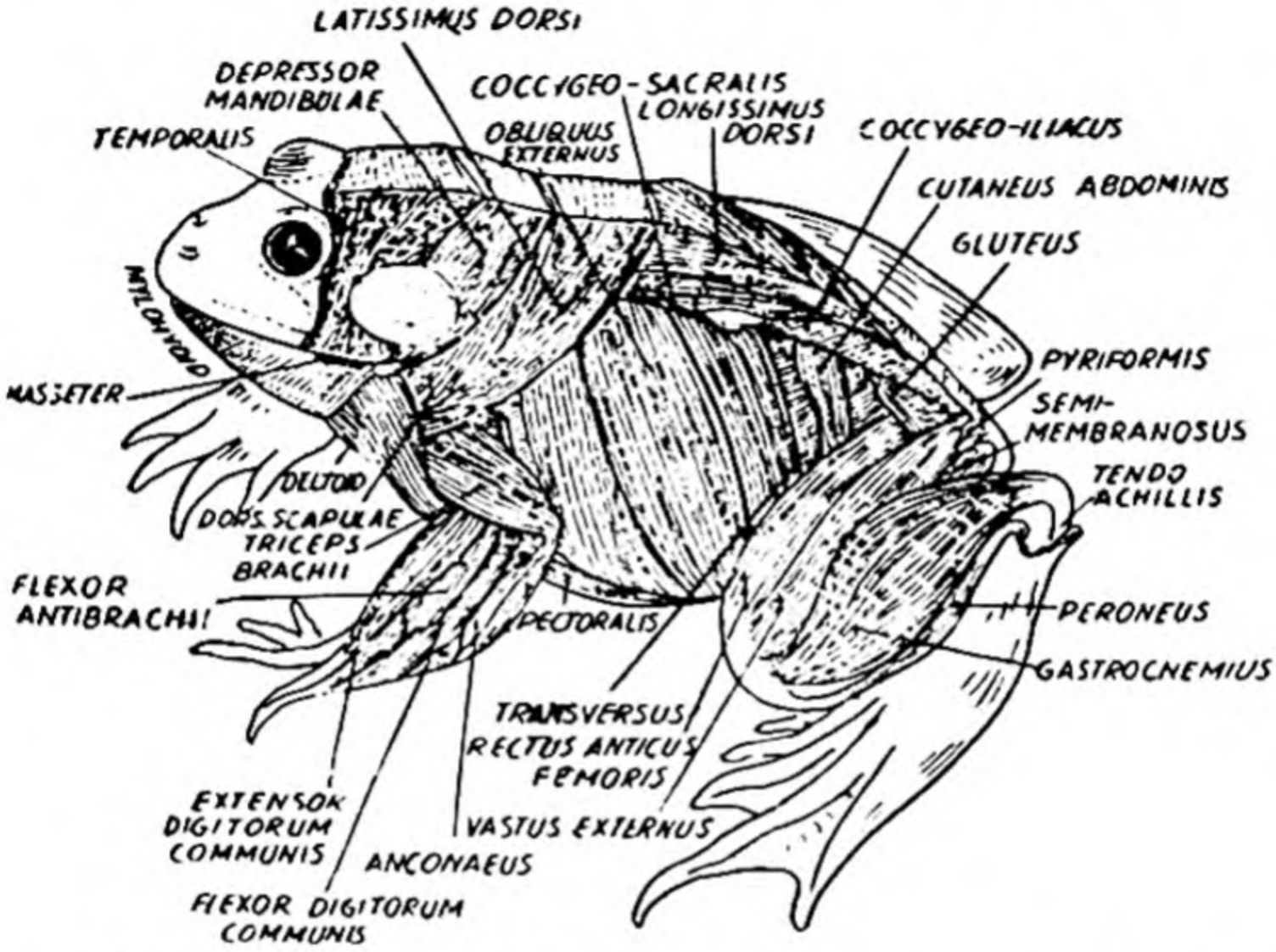

Fig. 27. Dorso-lateral view of the muscular system of a frog. (From Storer).

the spinal cord to the trunk-line and the nerves to the smaller lines. The nerves are everywhere intermingled with the muscles and carry the stimuli or messages from the brain to them, and also in the reverse direction.

Most of the muscles are attached by both ends to bones by means of strong, inelastic connective tissue bands known as *tendons*. When the muscle contracts, the bones, if they are united by a movable joint, are pulled nearer together, resulting in the movement of the part concerned.

To understand fully the production of movement through mus cle contraction, let us take up the calf-muscle of the frog

known as the *gastrocnemius* (Fig. 27). It is attached at the proximal end, by a band-like tendon, partly to the distal end of the femur and partly to the proximal end of the tibio-fibula. The tendon at the distal end of the muscle is a stout cord, known as *tendo Achillis*, which passes over the ankle-joint and spreads out into a broad sheet over the under-surface of the foot. When the frog is in the ordinary squatting position with the foot bent upon the shank, the effect of the contraction of the muscle is the *extension* of the foot so as to come into line with the shank. If the action is quick enough it will cause the frog to leap. It should be noted that the proximal tendon of the muscle is attached to a relatively immovable part (the femur and the tibio-fibula) while the distal tendon is united to a more movable part (the foot). The former is known as the *tendon of origin* and the latter as the *tendon of insertion*. Besides causing extension of the foot the gastrocnemius bends the leg at the knee-joint. This movement is known as *flexion*. The gastrocnemius, therefore, has a double function. It is an *extensor* of the foot and a *flexor* of the leg.

Types of Muscles. Certain terms, in addition to the two mentioned above, are applied to muscles according to the type of movement which each one of them produces. A muscle which draws a part nearer the long axis of the body is called an *adductor*, one which moves it away an *abductor*. A muscle which raises a part is a *levator*, one which lowers a part a *depressor*. A muscle which causes a part to rotate upon another is called a *rotator*. And lastly a circular muscle which closes an aperture or a tube is known as a *sphincter*.

It will, thus, be seen that the movements of the frog are not so simple as may appear at first sight. The greater the range of movement the larger is the number of muscles involved in producing it. The hip-joint, for instance, is worked by no fewer than nine muscles arising from the hip-girdle and inserted into the femur. The number of muscles in the body of the frog

is so large and their arrangement so complex that to attempt their detailed study would be beyond the scope of the present elementary book on Zoology. Some idea, however, of the variety of the muscles and the complexity of their arrangement may be had from Fig. 27.

CHAPTER VIII

THE FROG (*continued*)

THE DIGESTIVE SYSTEM

The *digestive system* is concerned with the conversion of food into the tissues of the body, and into energy. The process involves taking in of food, its digestion, absorption and assimilation, and final elimination of the undigested part. The digestive system consists of the *alimentary canal* and the *digestive glands*.

The Alimentary Canal.—The *alimentary canal* (Fig. 30), which begins at the *mouth* and terminates at the *cloacal aperture*, is a long coiled tube, narrow at some places and wide at others. It is suspended in the body-cavity by a portion of the visceral layer of the peritoneum, known as the *mesentery*. The mouth lies between the upper and the lower jaws of which the latter can move freely, by a hinge-joint, in a vertical plane.

The mouth leads into a wide cavity, the *buccal cavity* (Fig. 28), on the floor of which is the fleshy *tongue*. As already seen, the tongue is attached in front and free at the hind end which is bifid, that is, produced into two lobes. The part which the tongue plays in capturing the prey has already been described. A pair of openings, the *internal nares*, is situated in the anterior region of the roof of the buccal cavity. They communicate with the external nares already observed on the snout. Behind the anterior border of the upper jaw are three depressions, one *median subrostral fossa* and two *lateral subrostral fossae*. They help to close the mouth firmly during respiration. In the centre of the roof of the buccal cavity is a pair of bulgings formed by the large eyes. Just behind the tongue is an oval elevation with a median longitudinal slit, the *glottis*, which leads into the lungs. The posterior narrow, folded part of the buccal cavity is the *pharynx* which opens into the *gullet*. In

each angle of the mouth is an opening leading by a tubular passage to the inner surface of the tympanic membrane. The

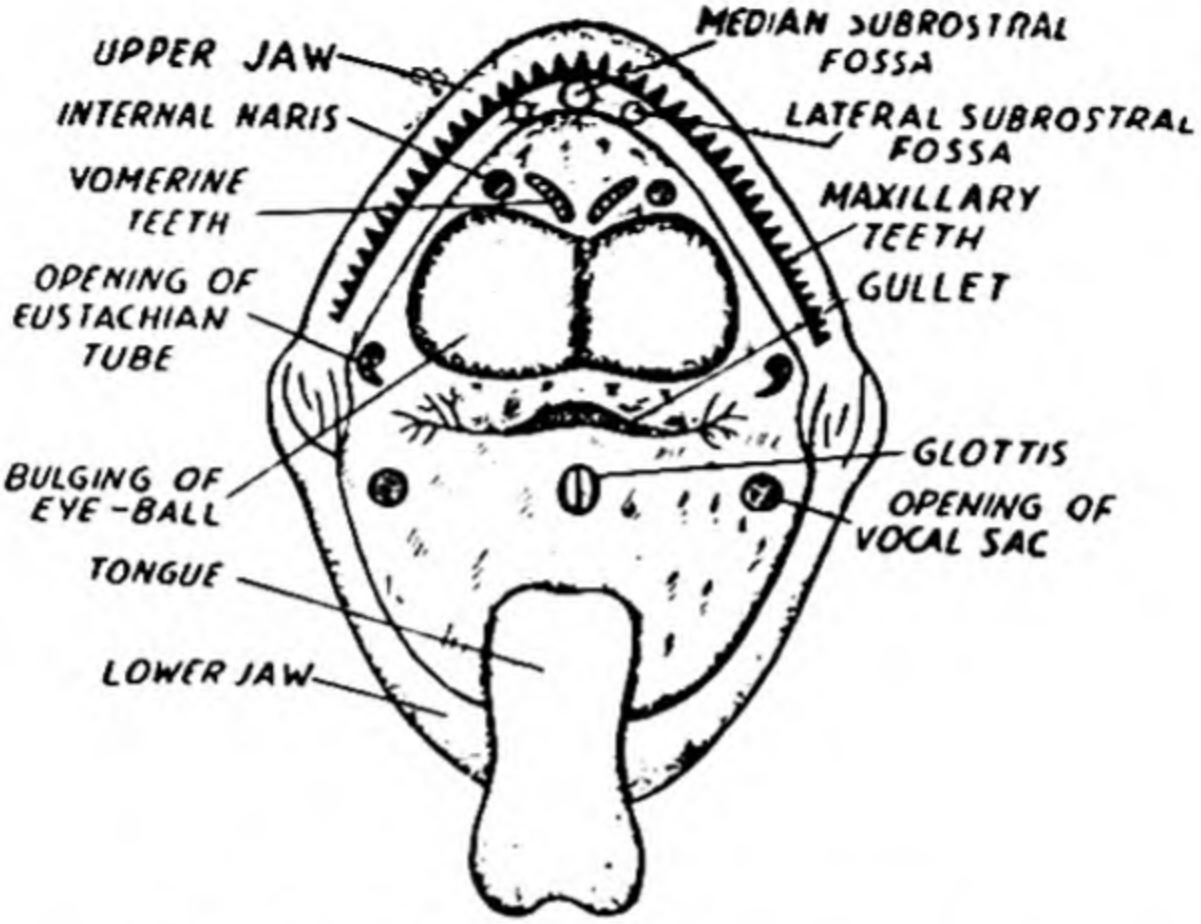

Fig. 28. The buccal cavity of a frog.

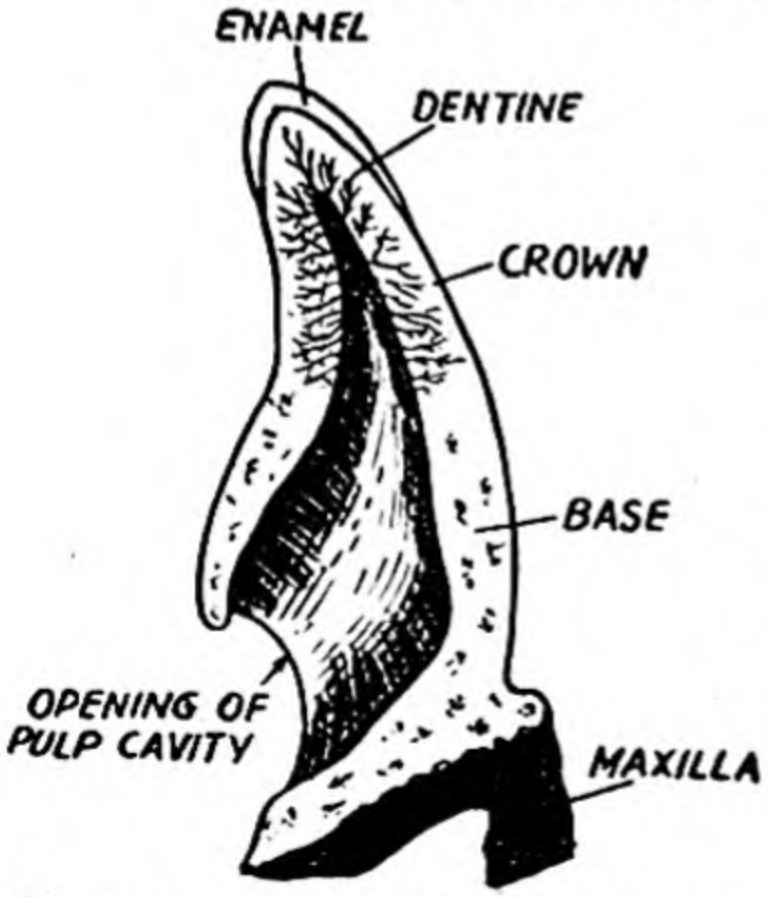

Fig. 29. A vertical section through a tooth and a part of the maxilla of a frog. (After Borradaile)

passage is known as the *Eustachian tube*. In the male frog the two openings of the vocal sacs are seen in front of the apertures of the Eustachian tubes.

There are no teeth in the lower jaw but the upper jaw bears, along its border, a semicircular row of small conical teeth, known as the *maxillary teeth*. Two small sets of *vomerine teeth* are found on the anterior part of the roof of the buccal cavity, one on either

side of the median line. The teeth are used only to prevent the escape of the prey and not for mastication. They are all alike, and are not embedded in sockets, as in our own case, but are fixed to dental processes on the jaw-bones by a cement. The old teeth are continuously replaced by new ones. Each tooth has in the centre a cavity, the *pulp cavity*, which contains blood vessels, connective tissue and nerve fibres. They constitute the *pulp* which nourishes the growing tooth. The structure of a tooth can be best studied in a vertical section (Fig. 29). It consists of two parts, a *base* and a *crown* The base is composed of a bone-like material while the crown of a substance called *dentine*. The distal half of the crown is covered with a layer of a very hard and resistant substance known as *enamel*.

The *pharynx* leads into the *oesohagus* or *gullet* which, due to the absence of a neck in the frog, is short and wide. It opens into the *stomach* which is a large thick-walled tubular sac lying on the left side of the body-cavity. Its anterior end is known as the *cardiac end* and the posterior as the *pyloric end*. The wall of the stomach at the pyloric end is thickened to form a constriction known as the *pyloric valve*. It allows only a small quantity of food to pass through at a time. The inner wall of the stomach is thrown into longitudinal folds which enable the stomach to be considerably distended. They are, therefore, well marked when the stomach is empty and disappear when it is full. The stomach opens into the *duodenum*, which is the first part of the small intestine, through the pyloric valve. The duodenum runs forward to lie paralled to the stomach Between the two limbs of the U, thus formed, lies a digestive gland, the *pancreas*. The duodenum is continued posteriorly into the coiled *ileum*, the two constituting the *small intestine*. The inner lining of the wall of the duodenum is folded in the form of an irregular net-work but in the ileum the folds become longitudinal. True villi, found in the higher vertebrates, are absent. The

ileum opens abruptly behind into the *large intestine*, the posterior part of which is known as the *rectum*. It leads into

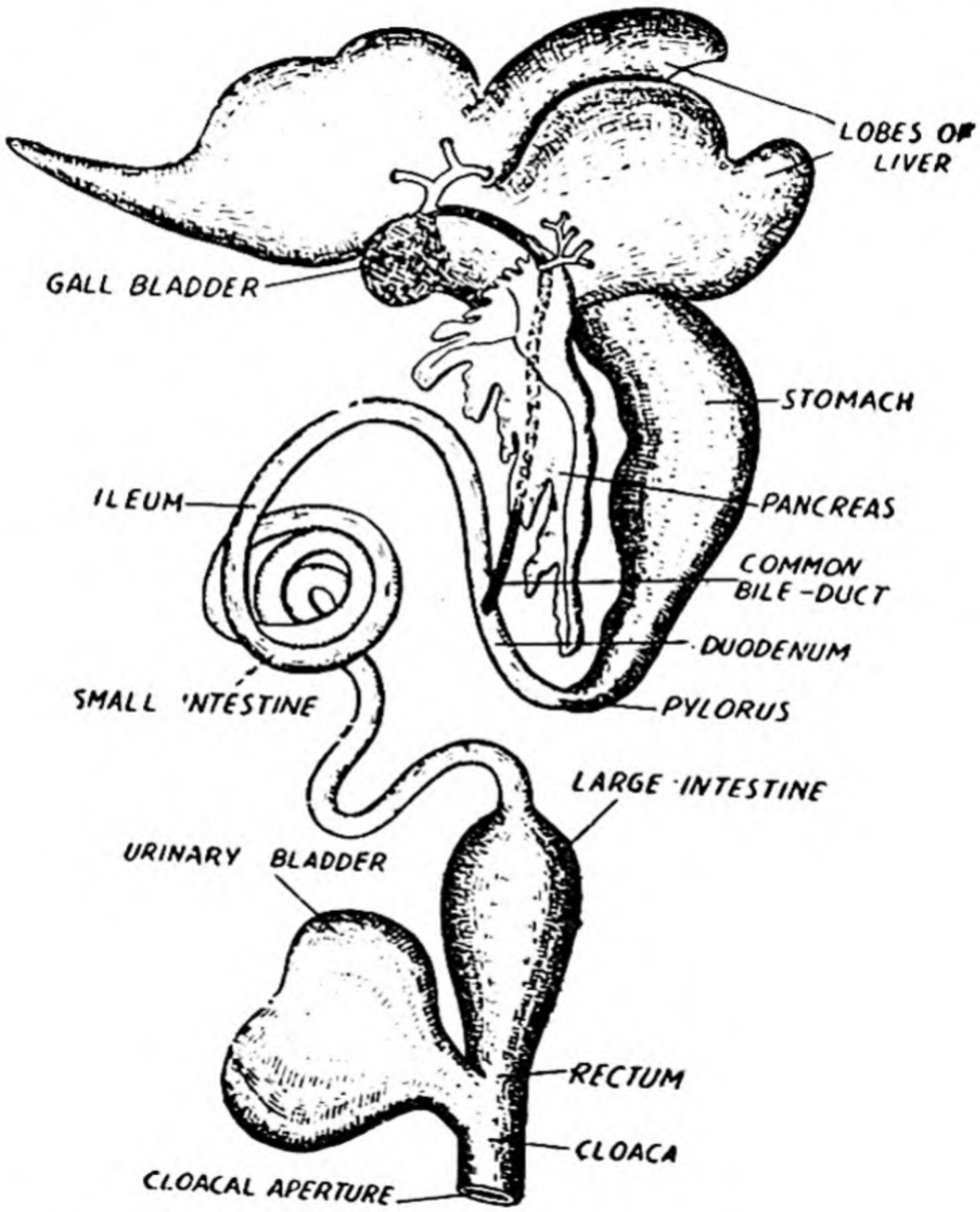

Fig. 30. The digestive system of a frog.

a terminal chamber, the *cloaca*, which opens to the outside by

the *cloacal aperture*. The cloaca is used not only for the elimination of the undigested food or faeces but also for the passage of urine and the reproductive products—ova or sperms as the case may be.

The food is pushed back through the alimentary canal by the squeezing movements of the walls of the latter. These movements are known as *peristaltic movements* or *peristalsis* (Fig. 31). In this process the muscular wall of the alimentary canal just in front of a mass of food contracts and pushes it backwards into the next part. Then the wall of this part contracts and pushes it still further and so on. Thus by a wave of contraction the food is moved along.

Fig. 31. Peristaltic movements

Digestive Glands. Any cell or group of cells that manufactures or *secretes* a product for the use of the organism is known as a *gland*. The most prominent glands associated with the digestive system are the *liver* and the *pancreas*. Digestive glands are also present in the walls of the stomach and the intestine. Salivary glands, found in man and other animals, are absent in the frog.

The Liver. The *liver* is a large reddish brown gland situated in the body-cavity in the region between the fore-limbs. It consists of two main lobes, a right and a left. The left lobe is further divided into two lobes. Between the two main lobes on the dorsal side is a thin-walled round sac of a greenish colour, the *gall-bladder*. It stores the secretion of the liver, known as the *bile*, which is green in colour and which is visible through the transparent wall of the gall-bladder. The bile is brought to the gall-bladder from the liver by the *hepatic ducts* and taken away to the alimentary canal by a *common bile-duct*. Small hepatic ducts open directly also into the common

bileduct, which passes through the substance of the pancreas and finally opens into the duodenum.

The Pancreas. The *pancreas* is an elongated gland, irregular in shape, and situated in the U formed by the stomach and the duodenum. Its secretion is known as the *pancreatic juice*, which is poured into the common bile-duct by a main *pancreatic duct* and several smaller ducts.

Nature of Food. The food of the frog consists mainly of insects, spiders and worms. The bodies of these animals are built up from protoplasm. The food of the frog, thus, contains practically the same compounds as are found in the protoplasm, namely, *proteins*, *carbohydrates*, *fats*, *mineral salts* and *water*. The function of food is to build up tissues and yield energy. The alimentary canal, as we have seen, is a continuous tube, open only at the two ends. It has no direct communication with the other parts of the body. The food which has passed through the alimentary canal may be said to have remained outside the body of the animals. How, then, does it reach all parts of the body to nourish them? The fact is that it actually passes through the lining membrane or *mucous membrane* of the intestine and enters the blood, which, as we will learn later, circulates throughout the body taking nourishment to every part. The spread of fluids in this manner is known as *diffusion*. There are, however, only a few food-stuffs, like sugars and mineral salts, which can diffuse through the mucous membrane, and that too in the form of solutions. The food of the frog, thus, may be classified into two groups, *diffusible* and *non-diffusible*. Sugars, mineral salts and water are diffusible whereas proteins, starches and fats are non-diffusible. The major part of the frog's food is non-diffusible. It must be converted into a diffusible form before it can be of any use to the animal. Let us see how this object is achieved.

Digestion. The conversion of non-diffusible food-stuffs into diffusible forms by the action of digestive juices or

otherwise is known as *digestion*. This change is brought about mostly by certain chemical substances in the digestive juices known as *enzymes* or *ferments*. Their chemical composition is not definitely known but they are organic in nature. They act as catalytic agents for they bring about chemical reactions without undergoing any change themselves. They are affected by changes in temperature and are destroyed if the temperature rises above 60°C. They generally work best at 30°C to 45°C. They are specific in their action, that is, each enzyme acts only on a particular food-stuff and only either in an alkaline or an acid medium. We will now describe the changes which the food undergoes during its passage through the alimentary canal.

As already stated there are nc salivary glands in the frog. The secretion of the salivary glands or saliva, in other animals, acts on the starch to change it into sugar. As the food of the frog does not have much starch in it and as it is not allowed to remain long in the buccal cavity but is immediately swallowed, the salivary glands, even if they had been present, would not have been of much use to the animal. The food, therefore, undergoes practically no change before it reaches the stomach where it is broken down by the mechanical action of its muscular walls. In the mucous membrane of the stomach are embedded glands, the *gastric glands*, which secrete a digestive fluid, the *gastric juice*. There are small traces of hydrochloric acid in this juice which is, thus, acidic in reaction. It contains a ferment, known as *pepsin*, which acts on proteins, in an acid medium only, converting them into diffusible *peptones*. The carbohydrates and fats remain unchanged in the stomach. The hydrochloric acid sterilizes the food by destroying harmful bacteria. By the time the food has reached the pyloric end of the stomach it has assumed a semi-solid state. It passes slowly into the duodenum through the pyloric valve. Here it is acted on by two juices, the pancreatic juice and the bile. The *pancreatic juice*, which has an alkaline reaction, is the most

important digestive juice as it acts on all the three kinds of food-stuffs by three distinct enzymes, namely, *trypsin*, *amylopsin* and *steapsin*. Trypsin, like pepsin, acts on proteins and converts them into peptones, which, on further action, are broken up into simpler compounds, the most important of which are the amino-acids. Amylopsin changes starch into sugar and steapsin emulsifies fats and splits them into fatty acids and glycerine.

The *bile*, which is the secretion of the liver, is an alkaline fluid. It is poured into the duodenum by the common bile-duct. It does not contain any enzyme and, thus, has no chemical action on the food. It simply emulsifies fats, that is, breaks them up into exceedingly fine droplets, which can easily pass through the mucous membrane.

The *intestinal juice*, which is secreted by the cells in the wall of the small intestine, contains a ferment called *erepsin* which converts peptones and other products of protein digestion into amino-acids.

According to the nature of food-stuffs on which they act, ferments may be divided into three kinds · (1) *proteolytic*, which act on proteins, such as pepsin and trypsin, (2) *amylolytic*, which convert starches into sugar, such as amylopsin, and (3) *fat splitting* which split fats into fatty acids and glycerine, such as steapsin.

Absorption and Assimilation.—When the food has been digested, that is, converted into a diffusible form, it passes through the mucous membrane of the alimentary canal into the blood and lymph. This process is known as *absorption*. The conversion of absorbed food into living tissues of the body is called *assimilation*. There is hardly any absorption of the food in the buccal cavity or the oesophagus and just a little in the stomach The chief organ of absorption is the small intestine. For this reason it is long and coiled and its mucous membrane is thrown into folds to provide a larger absorptive surface.

After the useful substances in the food have been absorbed by the small intestine the remaining waste part passes into the large intestine. From here it enters the cloaca and is finally eliminated through the cloacal aperture.

Functions of the Liver Besides secreting bile, the digestive action of which has already been described, the liver has a number of other functions. The most important of these is to manufacture a carbohydrate, known as *glycogen*, out of the excess of sugar in the blood. Glycogen resembles starch found in plants and is often referred to as "*animal starch*". It is stored in the liver in the form of granules when food is plenty and used up when it is scarce, for instance, during the period of hibernation. Glycogen is comparatively insoluble and therefore, indiffusible. When required by the body it is converted, by a ferment in the liver, into *dextrose* which, being a kind of sugar, is readily diffusible. It is passed into the blood which carries it to various parts of the body. In addition to forming a reservoir of carbohydrate food the manufacture of glycogen by the liver maintains a fixed proportion of dextrose in the blood. The liver also stores, for future use, the excessive fat in the food in the form of droplets.

Another function of the liver is to aid in the excretion of urea, which is a constituent of urine. When proteins are decomposed ammonium salts are produced as waste-products and these are converted into urea in the liver to be utlimately eliminated by the kidneys. Another waste-product excreted directly by the liver is the haemoglobin of worn out red blood corpuscles contained in the bile pigments. These are carried with the bile into the intestine from where they are passed out with the faeces.

CHAPTER IX

THE FROG (*continued*)

THE ENDOCRINE GLANDS

The glands whose secretions, instead of being carried off by ducts, are poured directly into the blood are known as *endocrine glands* or *ductless glands*, and the process is called *internal secretion*. The secretions themselves are known as *hormones*. It should, however, be noted that the presence or absence of a duct has no direct relation to the production of hormones, for there are glands possessing ducts, like the pancreas, which produce important hormones.

At one time the endocrine glands were considered to be superfluous structures but it is now well known that at least some of them are absolutely essential for keeping the animal alive. During recent years the study of hormones has received serious attention from physiologists and the results of their investigations have been applied with success in the treatment of human diseases. The hormones in man have more or less the same properties as those in animals so that hormone extracts from the latter could be administered to make up their deficiency in the former. Although hormones are secreted only in small quantities at a time they are carried by the blood to distant regions of the body where they stimulate various physiological processes. The endocrine glands, thus, play an important role in regulating and co-ordinating the functions of different organs of the body without the control of the nervous system. Let us now take up some of the more important endocrine glands found in the frog.

The Pancreas. The *pancreas* (Fig. 30) has already been

described as a digestive gland secreting the pancreatic juice which leaves the gland mainly by the pancreatic duct. But, in addition to the pancreatic juice, it secretes a sugar-regulating hormone known as *insulin*. It is produced by groups of cells in the pancreas known as the *islands of Langerhans* (Fig. 32). The deficiency of insulin in the body causes the disease called *diabetes*

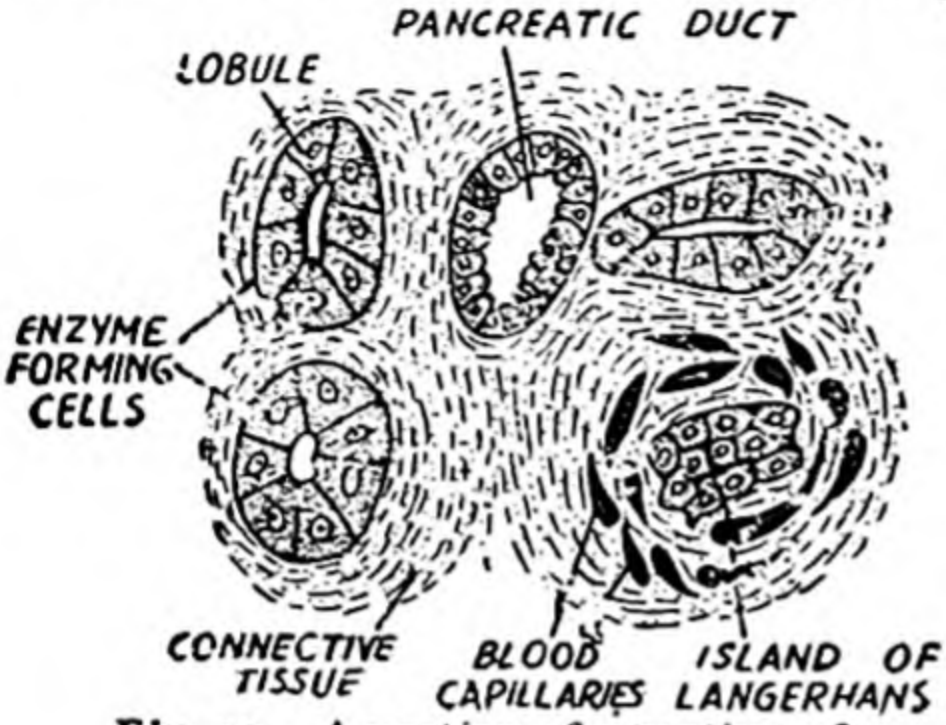

Fig. 32. A portion of a section of the pancreas.

which is quite common among human beings. In this disease there is an abnormal amount of sugar in the blood from where it is extracted by the kidneys and passed out with the urine. When insulin is injected into the blood of a diabetic patient the over-production of sugar is immediately checked. Normally, as we learnt in the last chapter, the excess of sugar in the blood is converted into glycogen by the liver and stored in its cells. It, therefore, follows that insulin stimulates the glycogen-forming function of the liver and its deficiency retards it.

The Spleen. The *spleen* (Fig. 11) is a small rounded body of a dark red colour, attached to the mesentery and lying close to the anterior end of the large intestine. It consists of a soft pulpy substance with an outer covering of a fibrous membrane and containing several kinds of cells. It acts as a purifier of blood as it removes from the latter old, used up red blood corpuscles and foreign bodies like pigment and harmful micro-organisms. In the spleen new leucocytes are formed by the division of old ones as is evidenced from the fact that there are

more of them in the blood vessel leaving the gland than in the one entering it.

The Thyroid Glands. The *thyroid glands* (Fig. 33) are a pair of small glands lying one on either side of the hyoid apparatus at the base of the posterior cornu. Each thyroid consists of a mass of vesicles bound together by connective tissue and richly supplied with blood vessels. Each vesicle is lined by a single layer of epithelial cells and contains a clear colloidal substance.

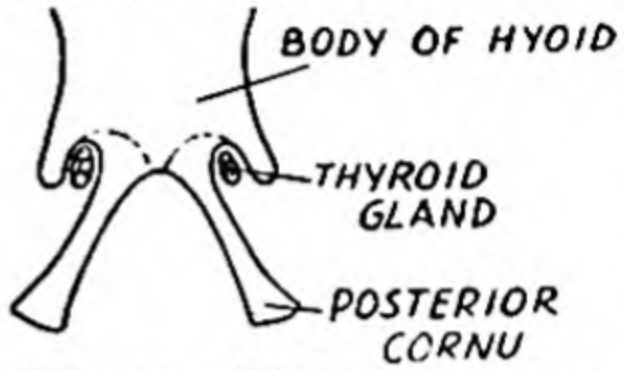

Fig. 33. Diagram showing the position of the thyroid glands.

As a result of numerous experiments performed on the larvae of frogs it has been established that the thyroid hormone, known as *thyroxin*, stimulates metamorphosis in them. Very small tadpoles when fed on thyroid extract ceased growing and were stimulated to transform themselves into miniature frogs before they had attained the normal size (Fig. 34). Thyroxin contains a large amount of iodine and it is probable that the hormonic properties of the thyroids are due mainly to this substance. In man functional disorder of the thyroids results in extreme mental deficiency, goitre and a poor development of the body. This condition is known as *cretinism*, which is treated by the administration of thyroid extract.

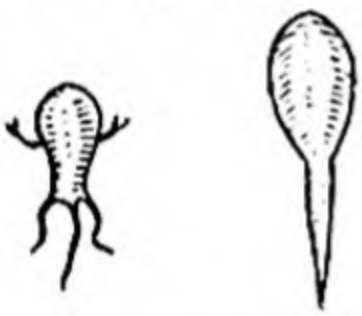

Fig. 34. Left, tadpole fed on thyroid ; right, tadpole of the same age not given thyroid.

The Thymus. The *thymus* (Fig. 35) is a paired gland of a reddish colour situated just behind the tympanic membrane, Nothing is known definitely about the function of this gland.

The Adrenal Bodies. The *adrenals* (Fig. 11) are a pair band-like yellowish glands lying on the ventral surface of the kidneys. They consist of differen kinds of cells arranged in

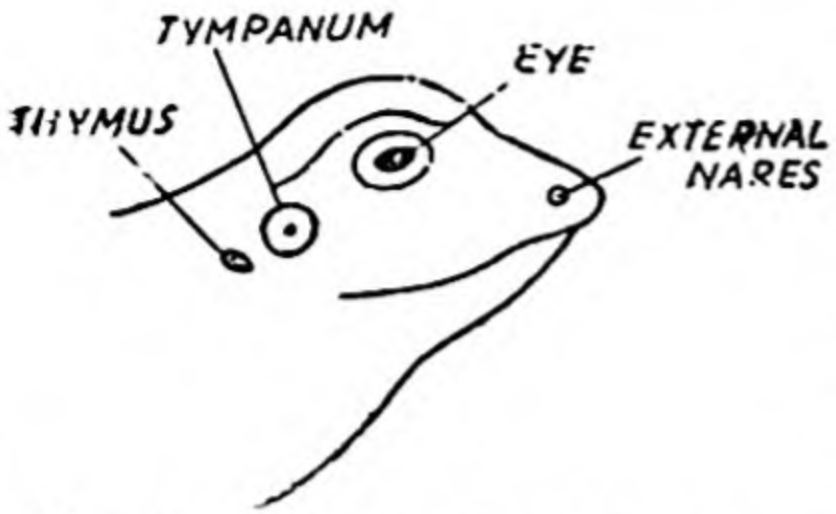

Fig. 35. Diagram showing the position of the thymus.

groups. It has been shown by experiment that a frog cannot live for more than few days if both the adrenals are destroyed. The hormone of the adrenals is known as *adrenalin* which increases blood pressure by causing the muscles of the blood vessels to contract. Due to

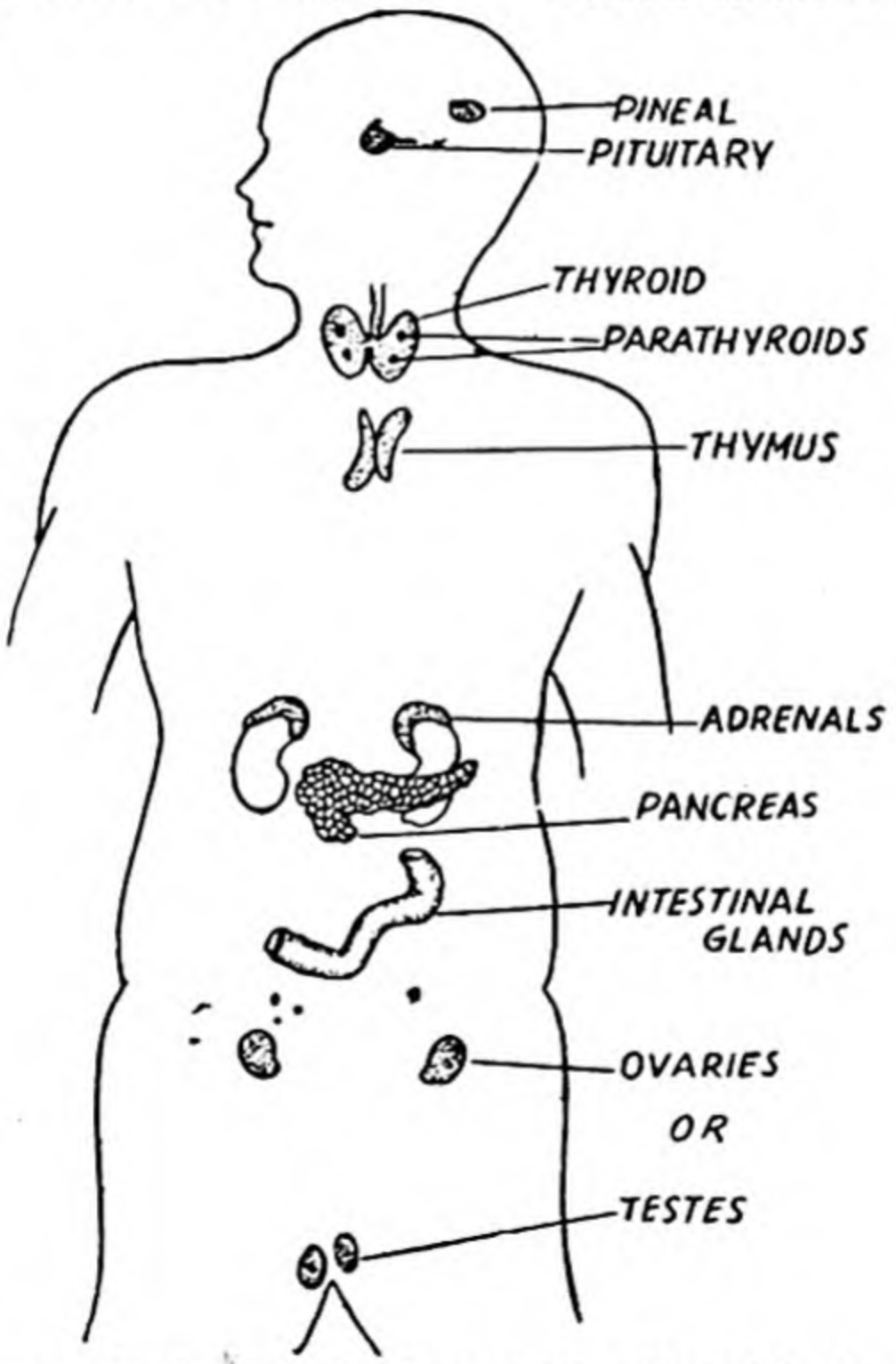

Fig. 36. Endocrine glands in man, (From Macdougall and Hegner)

this property adrenalin is commonly used in surgical operations.

The Pituitary Body. The *pituitary body* lies on the floor of the skull on the ventral surface of the brain. It consists of an anterior and a posterior lobe. It produces a number of hormones. It has been found that if the pituitary body of a tadpole is removed the latter shows slowness of growth, retardation of metamorphosis and a conspicuous paling of the skin. The development of the thyroid glands also is adversely affected. In man the influence of the pituitary body on growth is so great that its over-development produces a giant whereas insufficient pituitary secretion is the direct cause of a person remaining dwarf.

CHAPTER X

THE FROG (*continued*)

THE RESPIRATORY SYSTEM

The *respiratory system* is concerned with *breathing* or *respiration* in which there is exchange of oxygen and carbon dioxide. An animal may live for a considerable period without food but it soon dies if it is unable to obtain oxygen. We have learnt in a previous chapter that one of the objects of taking food is the production of energy which is essential for carrying on the vital activities of the body. This energy is produced when substances derived from the assimilation of food are oxidized, that is, combined with oxygen taken in with the air during the process of respiration. The release of energy is accompanied by the production of carbon dioxide which, being a waste-product, is eliminated from the body. The respiratory exchange of gases in the frog takes place in three different regions of the body, namely, the lungs, buccal cavity and the skin. These three modes of respiration are respectively known as *pulmonary*, *buccal* and *cutaneous*.

Pulmonary Respiration. *Pulmonary respiration* takes place in the lungs which communicate anteriorly, by a pair of openings, with a median chamber, the *larynx*. Due to the absence of a neck in the frog there is no regular trachea as is found in our own case. The larynx of the frog, in fact, represents both the larynx and the trachea of other animals. It is, therefore, also called the *laryngo-tracheal chamber*. The larynx opens into the buccal cavity through the glottis which, as we have seen, lies behind the tongue in the pharyngeal region.

The Lungs. The *lungs* (Fig. 37) are a pair of oval, thin-

walled sacs lying in the anterior part of the body-cavity. They possess to a remarkable degree the power of distension. This can be demonstrated by inflating a lung through the glottis after emptying it of all air. Each lung is covered externally by the peritoneum. Its inner surface is raised into a network of ridges or *septa* which enclose a large number of small chambers known as *alveoli*. In this way the respiratory surface of the lungs is considerably increased which adds to their efficiency. The walls of the alveoli are abundantly supplied with blood vessels which break up into fine capillaries.

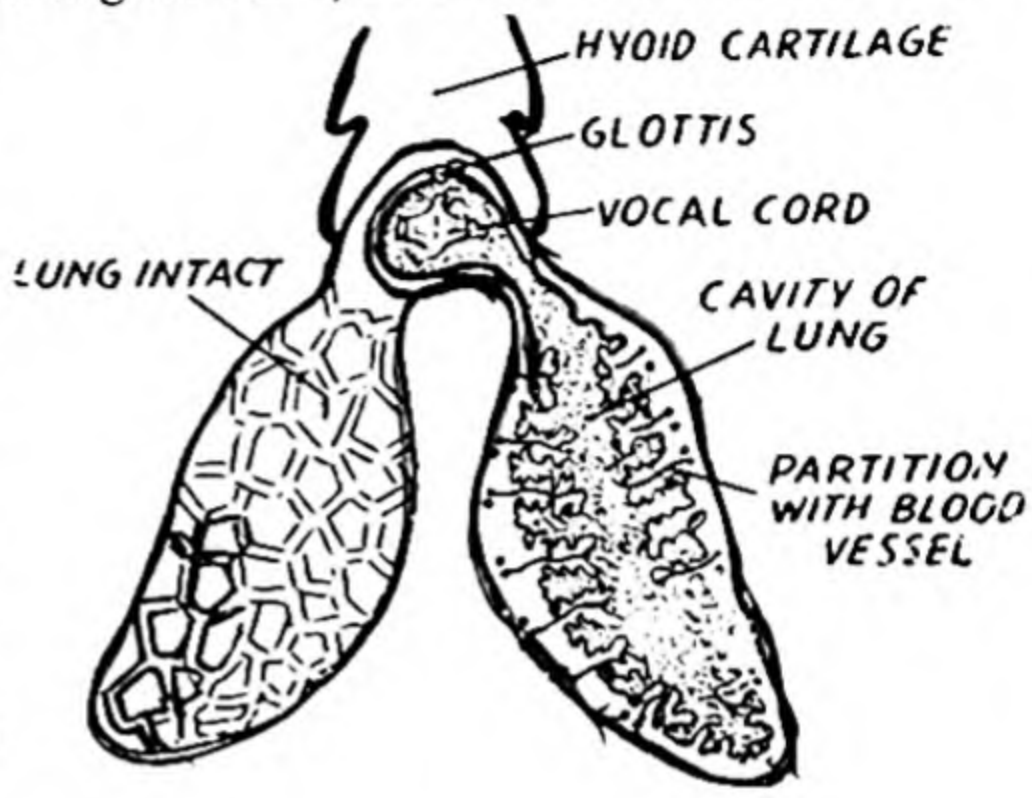

Fig. 37. The lungs of a frog

Mechanism of Pulmonary Respiration. If you watch a frog breathing you will notice that its mouth is kept closed and the throat falls and rises in a more or less regular manner. When the throat is depressed the buccal cavity becomes enlarged and a partial vacuum is created inside it. The result is that air from outside rushes in, to fill up the vacuum, through the external nares which are kept open. The air before reaching the buccal cavity has to pass through the olfactory chambers and the internal nares. This part of the respiratory act is known as *aspiration* (Fig. 38B).

The external nares are now closed by the elevation of the premaxillary part of the upper jaw, which is brought about by the tip of the lower jaw pressing upwards against the former.

It should be noted, in this connection, that the tips of both the upper and the lower jaws are independently movable. Soon

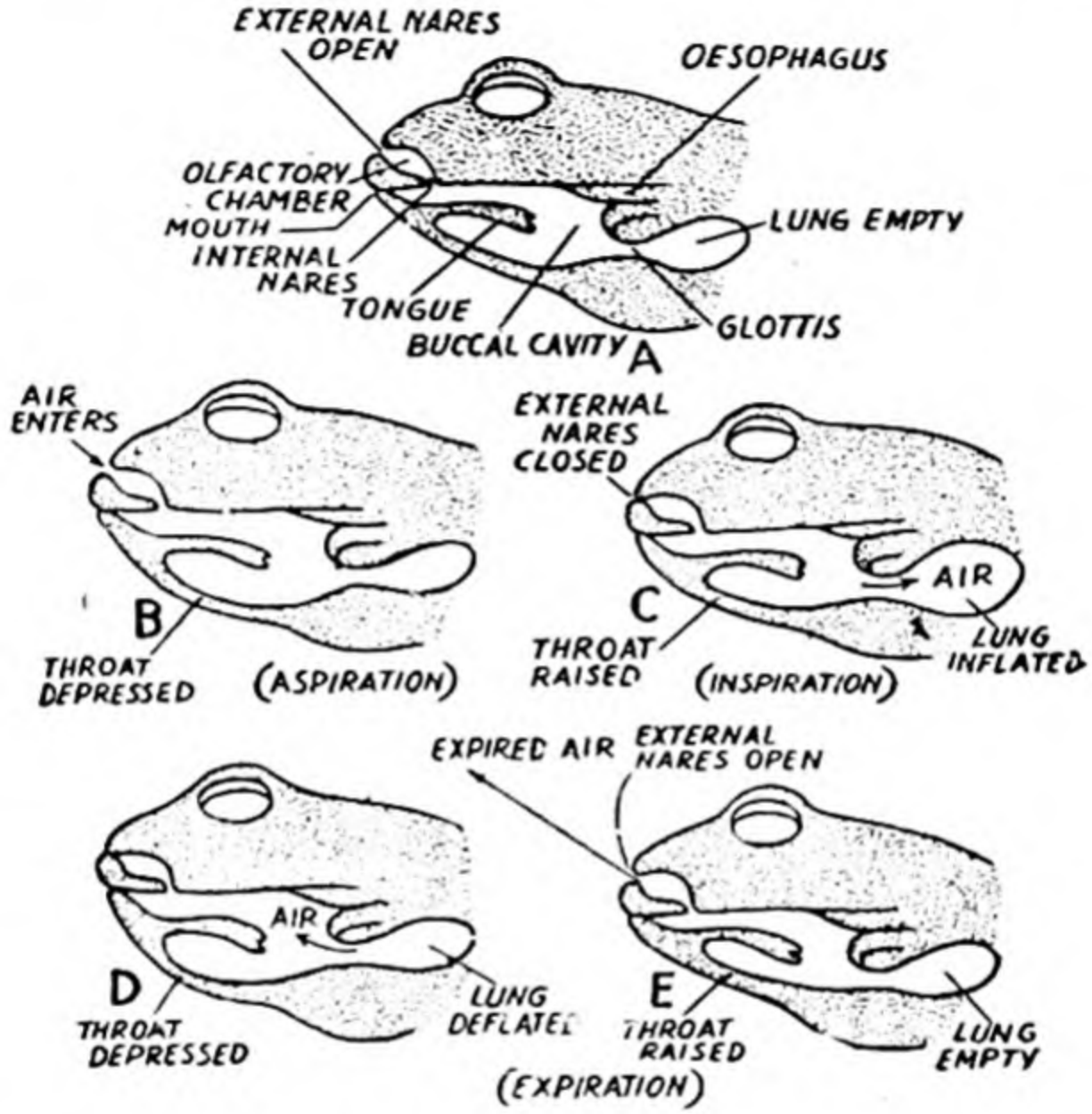

Fig. 38. Mechanism of pulmonary respiration in a frog.

after the closure of the external nares the floor of the buccal cavity is raised. The pressure on the air inside the buccal cavity is thereby increased and, there being no other outlet for escape, it forces upon the glottis, which ordinarily remains closed and enters the lungs after passing through the larynx. The buccal cavity, thus, acts as a force-pump driving the air into the lungs. This part of the respiratory act is known as *inspiration* (Fig. 38C).

The air, after it has given up its oxygen in the lungs, is

forced back into the buccal cavity partly by the contraction of the muscles of the body-wall and partly by the elasticity of the walls of the lungs. The glottis opens to let the air pass but closes immediately afterwards. At the same time the throat is lowered thereby enlarging the buccal cavity to accommodate the air coming from the lungs. Finally the air is expelled by raising the floor of the buccal cavity and opening the external nares. This part of respiration is known as *expiration* (Fig. 38 L-E).

As mentioned above, the mouth of the frog, during pulmonary respiration, remains tightly closed. If the buccal cavity is to function as a force-pump it must be made air-tight and that is possible only if the mouth is firmly closed. If the mouth is forcibly kept open the frog would not be able to breathe and would soon die due to lack of oxygen in the blood. The oesophagus also remains collapsed except when food is being swallowed.

Buccal Respiration. In *buccal respiration* exchange of oxygen and carbon dioxide takes place in the mucous membrane lining the buccal cavity, and the lungs take no part in it. As in the case of pulmonary respiration, the air is drawn into the buccal cavity through the external nares by lowering the throat. The air then is expelled from the buccal cavity by raising the throat. Thus by alternately lowering and raising the throat the air is inhaled and exhaled through the external nares. During buccal respiration the external nares are kept open and the mouth and the glottis remain closed.

Cutaneous Respiration. In the case of *cutaneous respiration* the exchange of gases takes place in the skin which is richly supplied with blood vessels. It has been mentioned in a previous chapter that the frog keeps its skin moist by frequent plunges into the water. We are now in a position to fully understand its significance. The thin film of water which covers the skin, when it is moist, contains oxygen dissolved in it. This

oxygen is exchanged with the carbon dioxide in the blood which flows through the capillaries of the skin. This explains why the skin of the frog is devoid of scales, feathers or hair, for, in the presence of any one of these coverings, it would not be able to function as a respiratory organ. It should be noted that cutaneous respiration is fundamentally different from the pulmonary or the buccal respiration. Whereas in the former oxygen is obtained from the water, in the latter it is obtained from the air. During hibernation the frog depends entirely on cutaneous respiration for the supply of oxygen.

Physiology of Respiration. We have just learnt that the object of respiration is the exchange of oxygen, which is essential for the vital functions of the body, and carbon dioxide, which is a waste-product and harmful to the body if retained inside for too long a period. To bring about this exchange of oxygen and carbon dioxide the air and the blood, which contain these gases, must come very close to each other. This is accomplished by the blood vessels breaking up into capillaries which spread out in the respiratory organs in the form of a net-work thereby increasing the surface of blood exposed to the action of the air. The walls of the capillaries are so thin that oxygen in the air and carbon dioxide in the blood pass through them by diffusion. It is, thus, obvious that the expired air contains less of oxygen and more of carbon dioxide than the inspired air. The exchange of gases in the respiratory organs, as outlined above, is known as *external respiration*.

The exchange of gases takes place not only in the respiratory organs but also in the tissues of the body. Every living cell requires oxygen, which it obtains from the blood, for its metabolic activities. These involve the oxidation of carbon compounds resulting in the production of carbon dioxide which is passed into the blood stream. The blood, thus, acts as a carrier of oxygen from the organs of respiration to the tissues and of carbon dioxide from the tissues to the organs of

respiration. The exchange of oxygen and carbon dioxide in the tissues is known as *internal respiration.*

Sound-producing Organs. The *sound-producing organs* in the frog are situated inside the *larynx*, a box-like chamber, which lies between the posterior cornua of the hyoid apparatus just in front of the lungs. The larynx opens behind into the lungs by a pair of apertures. At the anterior end it communicates with the pharynx through the glottis. The frame-work of the larynx (Fig. 39) consists mainly of the *cricoid* and *arytenoid cartilages.* The *cricoid cartilage* has the shape of a ring which is produced backwards into a spine. From either side of the ring arises a process, which is bent backwards to form a loop. The two processes are united with a transverse expansion of the cricoid lying on the ventral side of the larynx. The *arytenoid cartilages* are a pair of semi-lunar, valve-like structures, surrounded by the cricoid ring and supported from below by the transverse expansion of the cricoid.

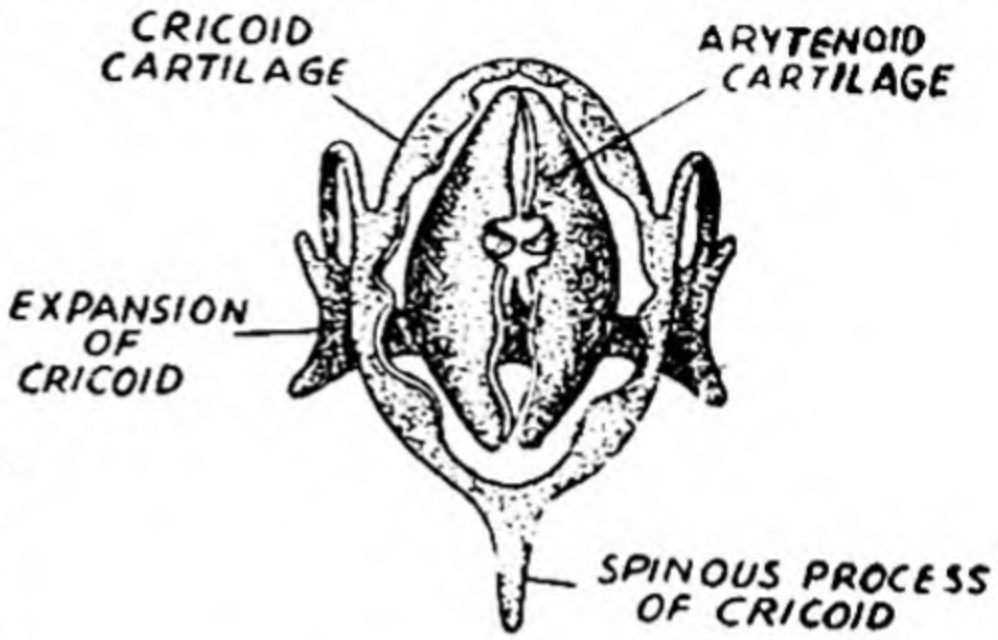

Fig 39. Cartilages of the larynx of a frog, dorsal view. (After Wiedersheim).

The true sound-producing organs are a pair of horizontal elastic bands, the *vocal cords*, running longitudinally in the middle of the larynx. The inner edges of the vocal cords lie close together in the middle line. The croaking of the frog is produced by the vibration of the free edges of the vocal cords caused by the expulsion of air from the lungs. The pitch of the sound can be varied by stretching or relaxing the cords.

through the action of muscles attached to the laryngeal cartilages. Reference has already been made to the vocal sacs present in the male frog. They are extensions of the harynxp and serve as resonators, that is, they reinforce and prolong the sound.

CHAPTER XI

THE FROG (*continued*)

THE VASCULAR SYSTEM

The main functions of the *vascular system* are to carry the digested food from the alimentary canal and oxygen from the respiratory organs to all parts of the body, and to collect carbon dioxide and other waste products from the tissues of the body and take them to the organs concerned, for their elimination. These functions are discharged by the *blood* which is pumped by the heart into closed tubes or *blood vessels* and carried to the remotest parts of the body from where it returns to the heart through another set of blood vessels. This process is continued so that the blood keeps circulating in the body ceaselessly till the time of death. The vascular system is, therefore, also known as the *circulatory system*.

Those blood vessels which carry the blood from the heart to various parts of the body are known as *arteries* and those which bring the blood back from the body to the heart are known as *veins*. The arteries which leave the heart are large vassels but they give off smaller vessels into the organs so that each one of them has its own artery. Inside the organ the artery branches repeatedly, the ultimate branches being extremely

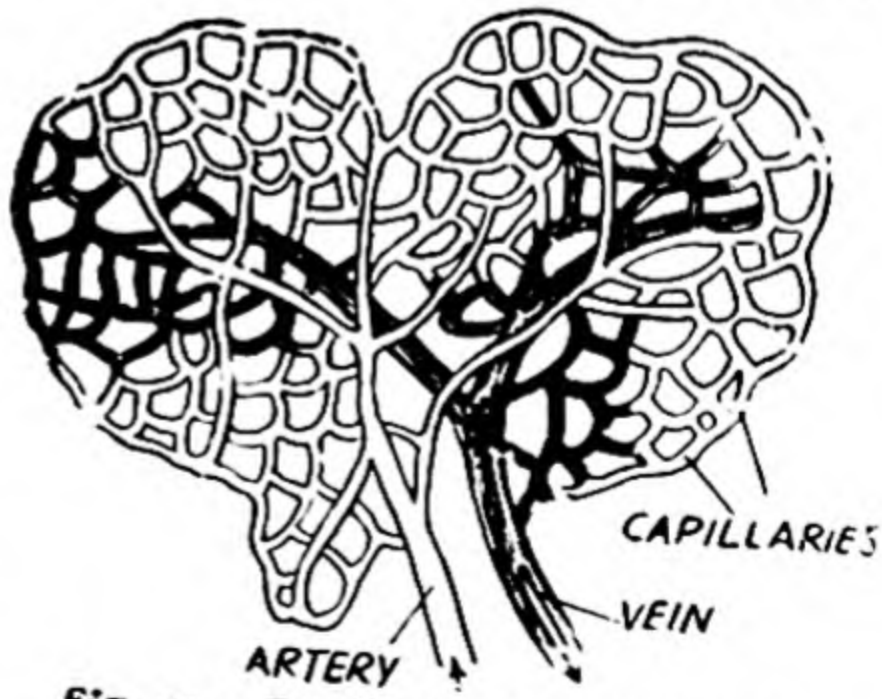

Fig. 40. Capillaries connecting an artery with a vein.

fine with exceedingly thin walls. These are known as *capillaries* (Fig. 40). The digested food, oxygen, carbon dioxide and other waste products can all pass through the thin walls of the capillaries by diffusion and it is, therefore, in the capillaries that these substances enter or leave the blood. The capillaries in each organ repeatedly reunite to form a vein which leaves the organ and joins a larger vein and in this manner all veins of the body ultimately unite to form venous trunks which open into the heart.

Structure of the Heart. The *heart* of the frog (Figs. 41 and 42) is a hollow, muscular, conical organ lying in the anterior part of the body-cavity on the ventral side. Its apex is directed backwards. The heart is enclosed in a double-walled thin bag, the *pericardium*. Its inner wall, which, closely invests the heart, is an extension of the visceral layer, and the outer wall of the parietal layer, of the peritoneum. The cavity between the two is known as the *pericardial cavity* which is filled by a fluid, the *pericardial fluid*. The latter protects the heart from injury and allows it free movement. As the pericardial cavity is contained within the two layers of the peritoneum it is a part of the body-cavity. It is continuous with the latter in the earlier stages of development but is completely cut off from it in the adult.

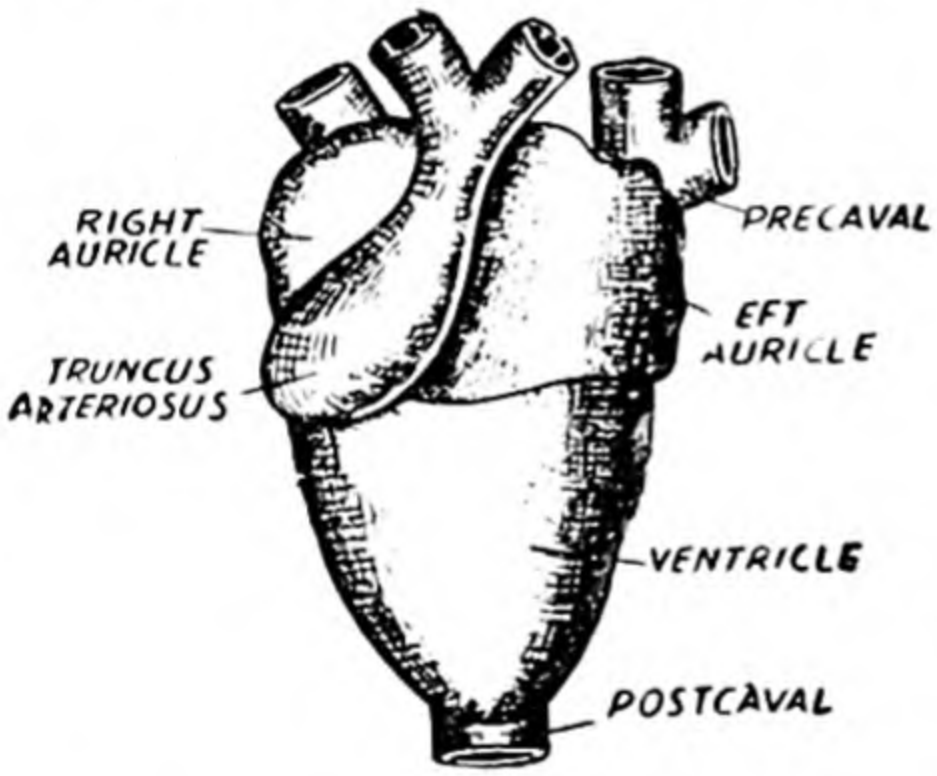

Fig. 41. Ventral view of the heart of a frog.

The heart consists of five chambers, namely, the *ventricle*, the *right* and *left auricles*, the *truncus arteriosus* and the *sinus*

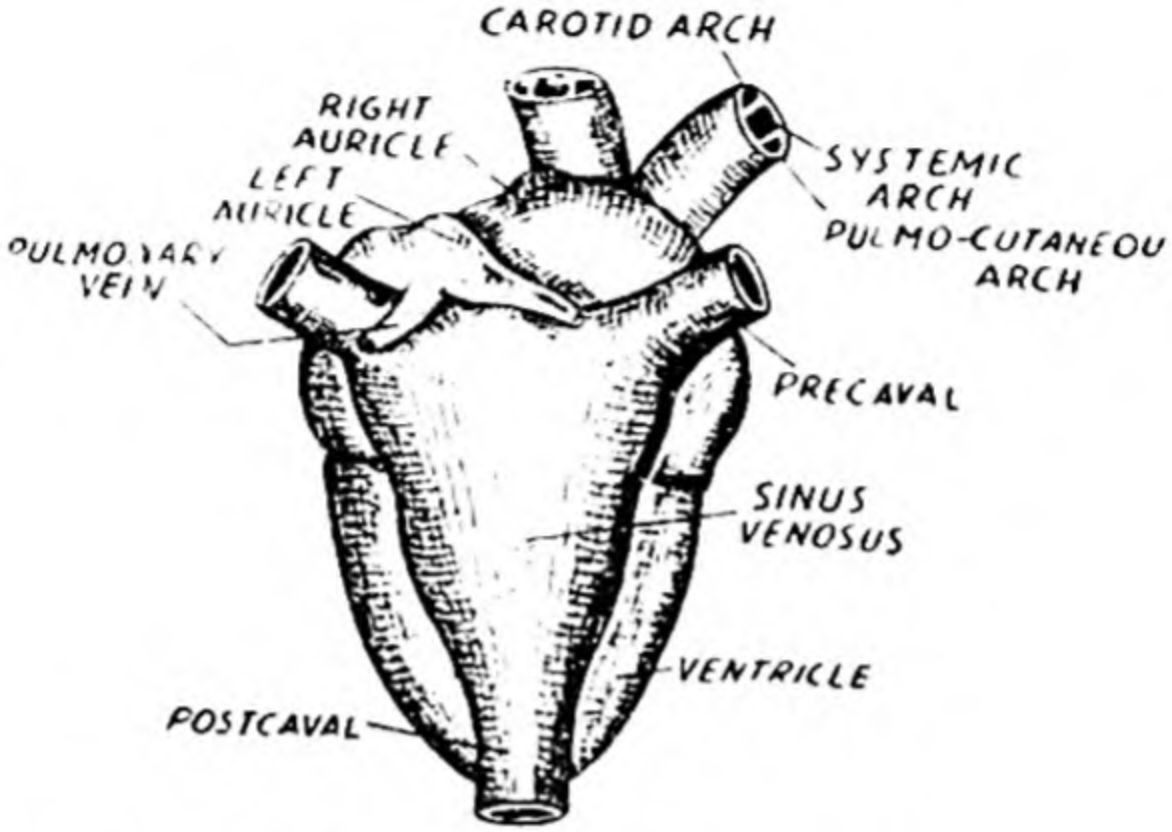

Fig. 42. Dorsal view of the heart of a frog.

venosus. The ventricle is the largest chamber and forms the apex of the heart. It has thick muscular walls. The two auricles lie in front of the ventricle. From outside they appear as one. They have thin walls. The truncus arteriosus is a tubular structure which arises from the right side of the anterior border of the ventricle on the ventral surface. It runs obliquely forward towards the middle line and divides into two main branches near the anterior boundary of the auricles. The sinus venosus is a thin-walled triangular chamber covering the greater part of the dorsal surface of the heart. Three big carval venous trunks enter the sinus venosus at its three corners.

The internal structure of the heart (Fig. 43) is fairly complicated. It is so designed as to propel blood only in one direction and, as far as possible, to prevent mixing of aerated and non-aerated blood. The two auricles, of which the right one is

the larger, are separated from each other by a wall or septum, known as the *inter-auricular septum*. In the dorsal wall of the

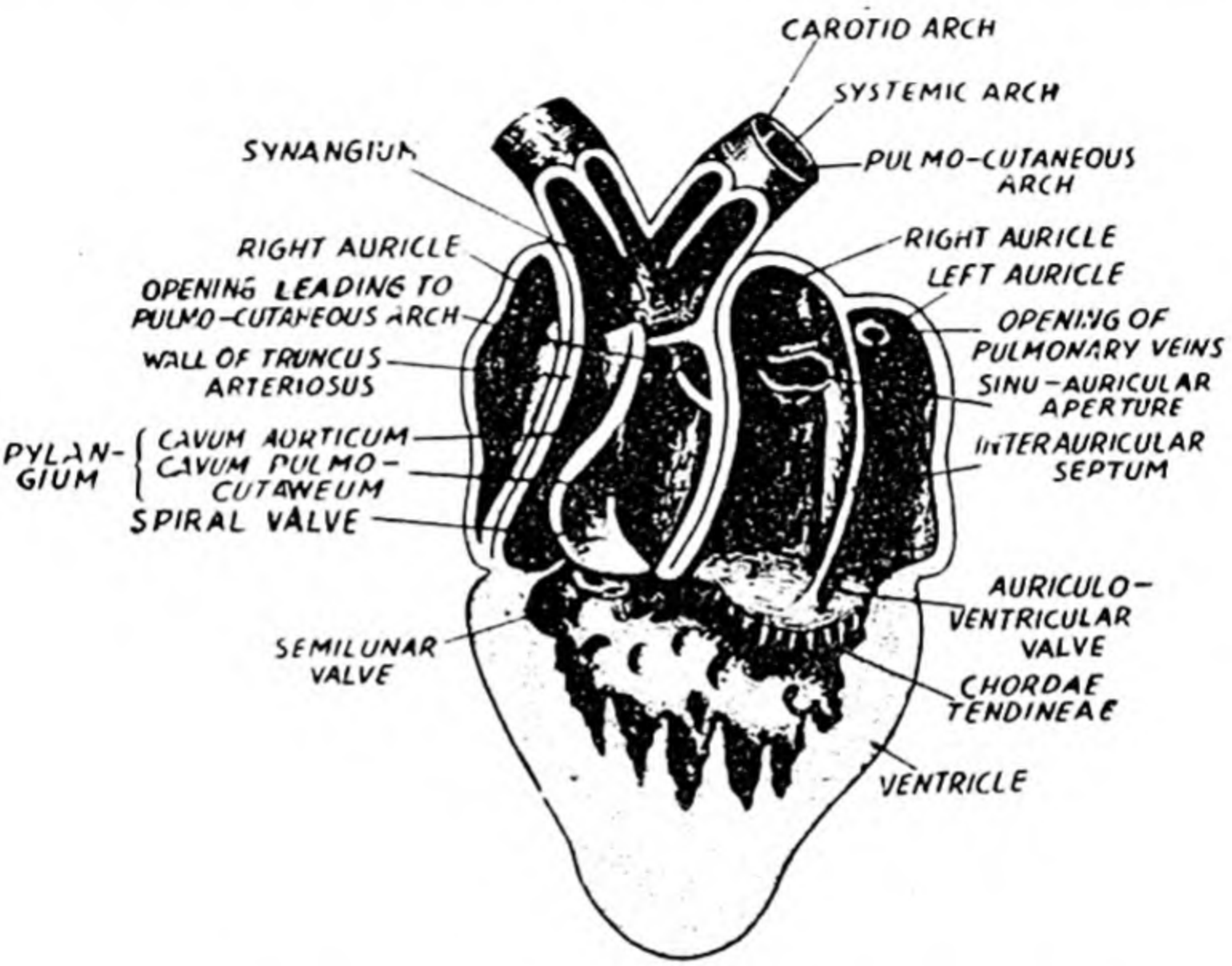

Fig. 43. Heart o the frog, with the ventral wall removed, to show the internal structure.

right auricle, close to the septum, is a large transverse, more or less oval, opening, the *sinu-auricular aperture*, through which blood from the sinus venosus enters the right auricle. This aperture is provided with two lip-like flaps or *valves*, the *sinu-auricular valves*, which allow the blood to pass freely from the sinus venosus into the right auricle but prevent its flow in the opposite direction, the pressure of the blood causing their free edges to meet, thus closing the aperture. The veins from the lungs, known as the *pulmonary veins*, open into the left auricle

by a small opening in its dorsal wall, towards the anterior end. It is not guarded by a valve but as the opening is oblique it is automatically closed by the contraction of the auricle and the blood prevented from flowing back into the pulmonary veins. The two auricles communicate with the ventricle by a common *auriculo-ventricular aperture* guarded by two flap-like *auriculo-ventricular valves* arising one from the dorsal and the other from the ventral edge of the aperture. The free edges of the valves are connected with the muscular wall of the ventricle by fine threads known as *chordae tendineae.* The valves work like ordinary folding doors opening in the direction of the ventricle. When the auricles contract the pressure of the blood forces apart the two valves and permits the blood an easy passage into the ventricle. If, on the other hand, the blood tends to flow back from the ventricle into the auricles the valves are brought together by the pressure of the blood from behind, thus closing the aperture. The chordae tendineae prevent the valves from being pushed in the auricles by too much pressure. The ventricle has thme muscular walls. Its inner surface is raised into longitudinal ridges, separated by deep fissures. As we will learn presently, the ridges prevent, to a large extent, the mixing of aerated and non-aerated blood coming from the left and the right auricles respectively.

The opening of the ventricle into the truncus arteriosus is provided with three *semi-lunar valves.* They have the form of small pockets with openings towards the truncus. When the blood passes from the ventricle into the truncus, the pockets are pressed flat against the walls of the latter, thus causing the aperture to open. The return of the blood into the ventricle, when the truncus contracts, is prevented by the pockets opening out and getting filled with blood and their edges meeting in the centre. The cavity of the truncus is divided into two unequal parts by a second row of semi-lunar valves. The long proximal part is known as the *conus arteriosus* or

pylangium and the short distal part *bulbus aorta* or *synangium*. The pylangium contains a spirally twisted longitudinal fold, the *spinal valve*, which runs obliquely and is attached to the wall of the pylangium by its dorsal edge while its ventral edge is free. The spiral valve is also attached anteriorly to one of the semi-lunar valves of the second row It, thus, incompletely divides the pylangium into a *cavum aorticum* which begins on the right side and curves round to the left to become ventral and a *cavum pulmocutaneum* which begins on the left si le and curves round to the right to become dorsal. The synangium is completely divided, by a horizontal partition, into a dorsal and a ventral chamber. The dorsal chamber communicates anteriorly with the *pulmocutaneous trunks*, going to the lungs and skin, and posteriorly with the cavum pulmocutaneum through an aperture guarded by a separate valve of its own. The ventral chamber of the synangium communicates anteriorly with the *systemic* and *carotid trunks*, going to the trunk and the head respectively, and posteriorly with the cavum aorticum.

Action of the Heart. We have already noted that the heart pumps the blood to all parts of the body. This is accomplished by the contraction of the muscular walls of the various chambers (*systole*) thereby squeezing the blood out of them, followed by their relaxation (*diastole*), when they regain their original side. This takes place in a regular sequence First the sinus venosus contracts, then the two auricles together, then the ventricle and lastly the truncus arteriosus. The arrangement of the valves, which have already been described, ensures the flow of the blood through the various chambers in the order named. When the sinus contracts the non-aerated blood, which it has received from the body, is driven into the right auricle through the sinu-auricular aperture. At the same time the left auricle receives aerated blood brought by the pulmonary veins from the lungs. The two auricles now contract together forcing the blood into the ventricle through the auriculo-ventricular

aperture, the backward flow of blood into the sinus being prevented by the sinu-auricular valves. The right side of the ventricle receives non-aerated blood from the right auricle and the left side aerated blood from the left auricle. The mixing of the two types of blood is prevented by the deep fissures in the wall of the ventricle. Some blood, however, in the middle part inevitably becomes mixed. When the ventricle contracts, soon after the auricles, the blood is forced into the truncus arteriosus, the auriculo-ventricular valves stopping its re-entry into the auricles. Since the opening of the truncus is situated on the right side of the ventricle the former first receives non-aerated blood which has two alternative routes to follow. It may go to the cavum pulmocutaneum and thence, through the dorsal chamber of the synangium, into the pulmocutaneous trunks or to the cavum aorticum and thence, through the ventral chamber of the synangium, into the systemic and carotid trunks. It takes the former course as the resistance, due to the shortness of the route and absence of obstructions, is much less than in the other case. Thus the non-aerated blood, which is the first to be received by the truncus from the ventricle, goes to the lungs and the skin to be oxygenated. When the pulmocutaneous trunks become filled with blood their resistance increases and, therefore, the remaining blood, mixed and aerated, passes through the cavum aorticum into the ventral chamber of the synangium. By this time the conus also starts contracting, bringing the free ventral edge of the spiral valve in contact with the wall of the pylangium. The result of this is that the cavum pulmocutaneum is completely cut off from the cavum aorticum as well as from the ventricle. From the ventral chamber of the synangium the blood again takes the path of least resistance. In the carotid trunks the blood is obstructed by the carotid labyrinths. Hence the mixed blood goes into the systemic trunks and thence to the viscera and the limbs. Finally, when the pressure in the

systemic trunks increases, the remaining blood, which is aerated goes to the carotid trunks to be carried to the head region. Thus the distribution of blood is very judicious, the aerated blood going to the brain, the mixed blood to the body and the non-aerated blood to the lungs and the skin.

Recent experimental work carried out by Vandervael and Foxon has revealed that the non-aerated blood from the right auricle and the aerated blood from the left auricle become mixed in the ventricle so that there is not, as hitherto believed any further separation of the two types of blood. X-ray opaque material was injected either into the sinus venosus or into the pulmonary veins, making it possible to watch the course of the circulation. It was noticed that the material was equally distributed along all channels leaving the heart, and the blood, thus, had more or less a uniform composition. In this connection it may be pointed out that pulmonary respiration in the frog is supplemented, to a considerable extent, by buccal and cutaneous respiration. The blood going into the sinus venosus, which includes that from the mouth and the skin, will not, therefore, be completely non-aerated. A mixture of this blood and the fully aerated blood from the lungs would probably be good enough for an animal of comparatively low metabolic activity like the frog.

Arteries and Veins. We have already learnt that the vessels carrying blood from the heart to the organs are the *arteries* and those returning the blood from the organs to the heart are the *veins*. We may now consider other characters which distinguished the arteries from the veins. The arteries almost always contain aerated blood while the veins contain non-aerated blood. A notable exception is found in the case of pulmonary vessels, for the pulmonary artery contains non-aerated blood and the pulmonary vein aerated blood. The flow of blood in the arteries is fast and jerky, corresponding to the heart-beats, whereas in the veins it is slow and steady. The

arteries are deep-seated, have thick elastic walls without valves and are empty after death. The veins are more superficial in

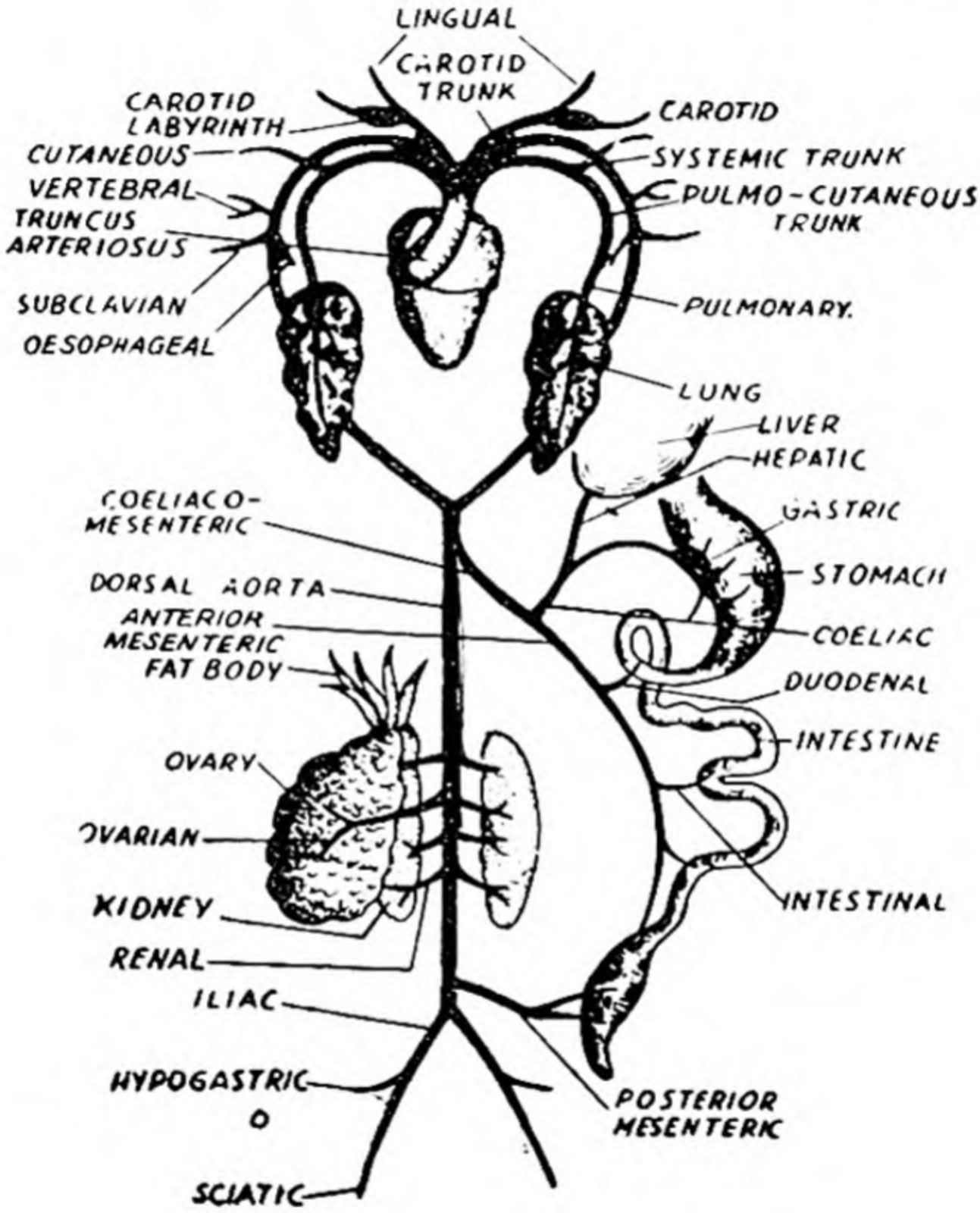

Fig. 44. Arterial system of the frog.

position, have thin collapsible walls with valves and are full of blood after death.

Arteries. It has already been stated that the truncus

arteriosus divides distally into two branches. These are known as the *aortic arches*. Each aortic arch divides almost immediately into three large arteries, namely, the *carotid trunk*, the *systemic trunk* and the *pulmocutaneous trunk* (Fig. 44).

The *carotid trunk* divides into two, a *lingual artery* going to the tongue and a *carotid artery* supplying, through small branches, arterial blood to various parts of the head. At the origin of each carotid is a small spongy swelling, the *carotid labyrinth*, consisting of minute vessels formed by the breaking up of the carotid artery. These re-unite to form the artery again which is continued forward towards the head.

The two *systemic trunks* curve upwards, backwards and inwards, round the oesophagus, to join each other in the middle line to form the *dorsal aorta* which runs backwards below the vertebral column in the subvertebral lymph sinus. Each systemic trunk gives off, before it reaches the dorsal aorta, a *vertebral artery* to the vertebral column and a part of the head, an *oesophageal artery* to the oesophagus and a *subclavian artery* which, after giving off branches to the shoulder and the body-wall, is continued into the fore-limb as the *brachial artery*. From the point of union of the two systemic trunks arises a large unpaired *coeliaco-mesenteric artery*, which runs backwards and divides into a *coeliac* and an *anterior mesenteric*. The former gives off a branch to the liver (*hepatic*) and another to the stomach (*gastric*), and the latter supplies the small intestine, spleen and the anterior part of the rectum. The dorsal aorta gives off four pairs of *renal arteries* to the kidneys and a pair of *spermatic arteries* to the testes or *ovarian arteries* to the ovaries as the case may be. A small artery, *posterior mesenteric*, which is given off from the aorta behind the kidneys, supplies the hinder part of the rectum. At the posterior end the dorsal aorta bifurcates into a pair of large *iliac arteries*. Each iliac, after giving off a small *hypogastric* to the urinary bladder, passes into the hind-limb as the *sciatic*.

Each *pulmocutaneous trunk* divides into two main arteries, the *pulmonary artery* going to the lung and the *cutaneous artery* branching extensively in the skin.

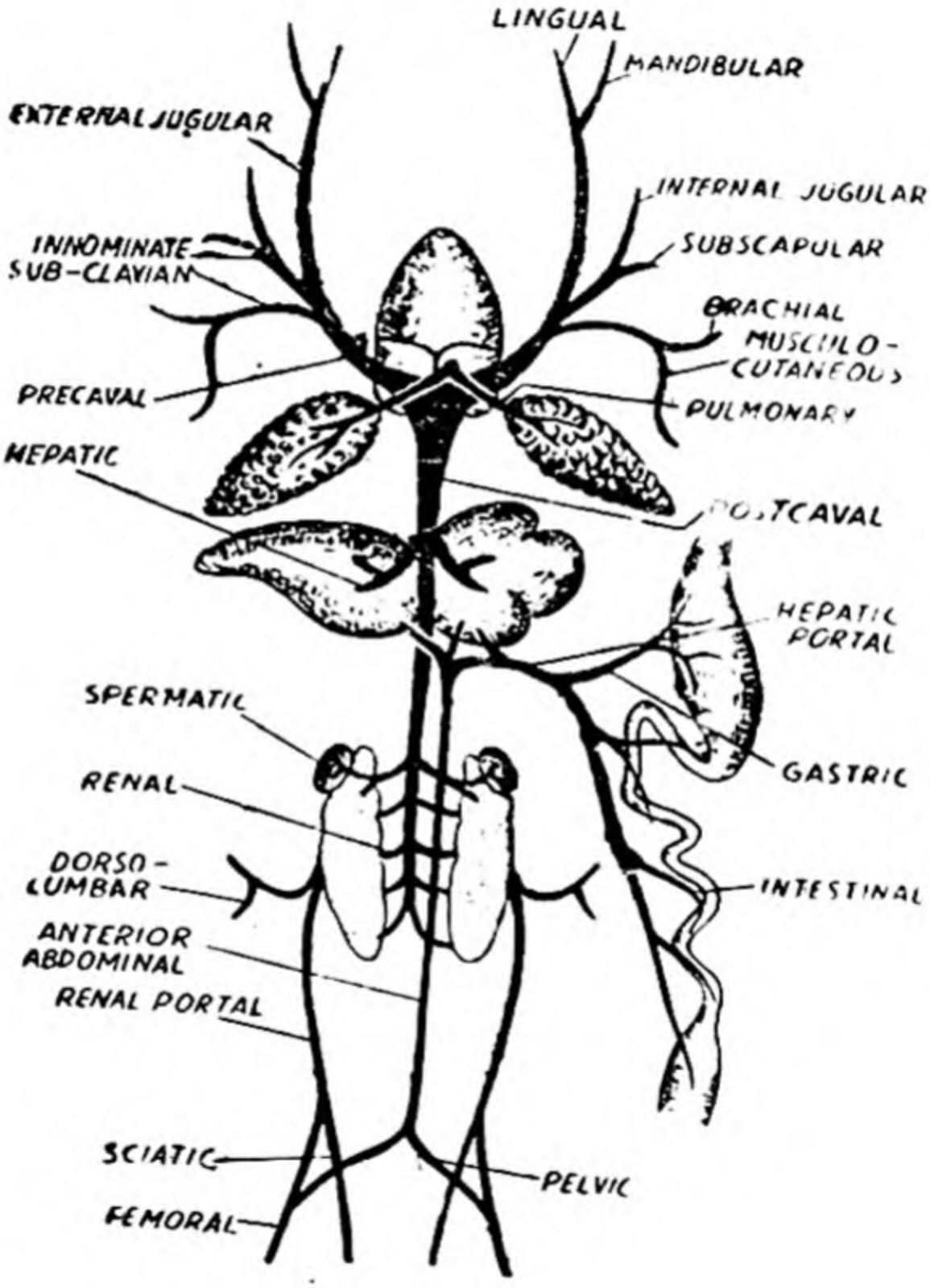

Fig. 45. Venous system of the frog.

Veins. Blood from all parts of the body, except the lungs, is brought to the sinus venosus by three venous trunks. Two of

them, which enter through the anterior angles of the sinus, are the *precaval veins* or *anterior venae cavae* and the third, which enters through the posterior end, is the *postcaval vein* or the *posterior vena cava* (Fig. 45).

Each *precaval* is formed by the union of three veins namely, the *external jugular*, the *innominate* and the *subclavian*. The external jugular receives the *lingual vein* from the tongue and the *mandibular vein* from the lower jaw. The innominate is formed by the confluence of the *internal jugular vein* from the brain, eye and other parts of the head, and the *subscapular vein* from the shoulder and back of the arm. The subclavian arises by the union of the *brachial vein* from the fore-limb and the *musculo-cutaneous vein* from the muscles of the trunk and superficial parts of the head, and the skin.

The *postcaval* is a large vessel lying in the middle of the trunk below the dorsal aorta. Posteriorly it receives five or six pairs of *renal veins* from the kidneys and, in the male, the *spermatic veins* from the testes or, in the female, the *ovarian veins* from the ovaries. Anteriorly it passes through the liver, receiving two *hepatic veins* from that organ, and finally opens into the sinus venosus.

The blood from each hind-limb is returned by two veins, an outer *femoral* and an inner *sciatic*. The femoral, on entering the trunk, divides into the *renal portal vein* and the *pelvic vein*. The renal portal vein is joined by the *sciatic vein* and going forwards receives the *dorso-lumbar vein* from the muscles of the back, before entering the kidney at its outer border. Inside the kidney the renal portal vein breaks up into capillaries which re-unite to open, along with the capillaries of the renal arteries, into the renal veins. The two pelvics unite to form the *anterior abdominal vein* which lies superficially in the mid-ventral line just below the skin. Anteriorly it enters the liver where it breaks up into capillaries. Veins from the stomach, intestine, pancreas and spleen unite to form a large *hepatic portal vein*

which, after sending off a branch to the anterior abdominal vein, enters the liver and breaks up into capillaries in that organ. The blood from the lungs is returned by the right and left *pulmonary veins* which unite before opening into the left auricle.

The Portal Systems. A vein which breaks up, on its way to the heart, into a set of capillaries in some intermediate organ, is known as a *portal vein*. A group of veins taking part in a portal circulation is known as a *portal system*. In the frog there are two such systems, namely, the *renal portal* and the *hepatic portal* so called because the second sets of capillaries lie in the kidneys and the liver respectively. The *renal portal system* consists of the femoral and sciatic veins from the hind-limb and the dorso-lumbar from the body-wall, all opening into the renal portal vein which, as already seen, enters the kidney at its outer margin. Each kidney, thus, receives blood from the renal arteries and the renal portal vein and sends it out through the renal veins which open into the postcaval. The *hepatic portal system* is constituted by the anterior abdominal vein and the hepatic portal vein, the latter receiving blood from the stomach, intestine, pancreas and spleen, through their respective veins, namely, the *gastric*, *intestinal*, *pancreatic* and *splenic*. The liver, thus, receives blood from three sources, namely, the hepatic artery, the anterior abdominal vein and the hepatic portal vein. The blood is collected from the liver by the hepatic veins which open into the postcaval.

The portal systems are of great value to the animal concerned. They act as short circuits enabling products in the blood to reach particular organs directly instead of first going to the heart and the respiratory organs. Thus the renal portal system enables waste products from the posterior part of the body to go straight to the kidneys to be immediately removed. In the same way the hepatic portal system enables the digested food from the stomach and the intestine to go at once

to the liver where excess of carbohydrates are removed from the blood and transformed into glycogen to be stored in the liver-cells. It also enables the liver to remove from the blood, without unnecessary delay, harmful ammonium salts produced during protein digestion, and convert them into urea, to be finally eliminated by the kidneys.

The Blood. The blood (Fig. 46) is a red fluid consisting of a liquid part, the *plasma*, and numerous cells or *corpuscles* which float in it. There are two main kinds of corpuscles, the *red corpuscles* and the *white corpuscles* or *leucocytes*.

The *plasma* is an almost colourless fluid of a very complex nature. Water forms about 80% of its whole mass. It contains various substances either in solution or suspension. These include the products of digestion, namely, sugar, soluble proteins, emulsified or decomposed fats, vitamins and a considerable number of salts. It also contains various gases such as oxygen, nitrogen and carbon dioxide, and a number of waste products chiefly urea and the products of broken down tissues, besides hormones secreted by the endocrine glands and antitoxins which have a protective function. All these substances do not, however, form an integral part of the plasma, but are simply carried by it from one place to another. They are, thus, constantly entering and leaving the plasma.

The blood when exposed to the air, or brought into contact with a foreign object, coagulates or forms a *clot* which separates from a pale yellow liquid, the *serum*. The clot consists of a net-work of fine fibrils, composed of a substance called *fibrin*, which is formed from a protein, *fibrinogen*, found in the plasma. The blood corpuscles get entangled in the fibrin net-work. The clotting of blood is a protective device. When bleeding takes place due to the rupture of a blood vessel it is stopped by the formation of a clot at the place of the injury.

The *red blood corpuscles* are nucleated and contain a pigment in the cytoplasm, known as *haemoglobin*, which is a kind of

protein. It gives the blood its red colour. It contains iron as one of its constituents. It is light yellow in colour but appears red when corpuscles are present in several layers. Haemoglobin has the property of readily combining with oxygen, forming an unstable compound known as *oxyhaemoglobin*. The latter easily gives up its oxygen changing back to haemoglobin. It has a red colour only in combination with oxygen otherwise it is purplish red. This explains why aerated blood is bright red and nonaerated blood deep purple. We have already learnt that blood carries oxygen from the respiratory organs to the tissues. This function of the blood is performed chiefly by the haemoglobin contained in the red blood corpuscles, the plasma carrying only a small quantity of the oxyzen.

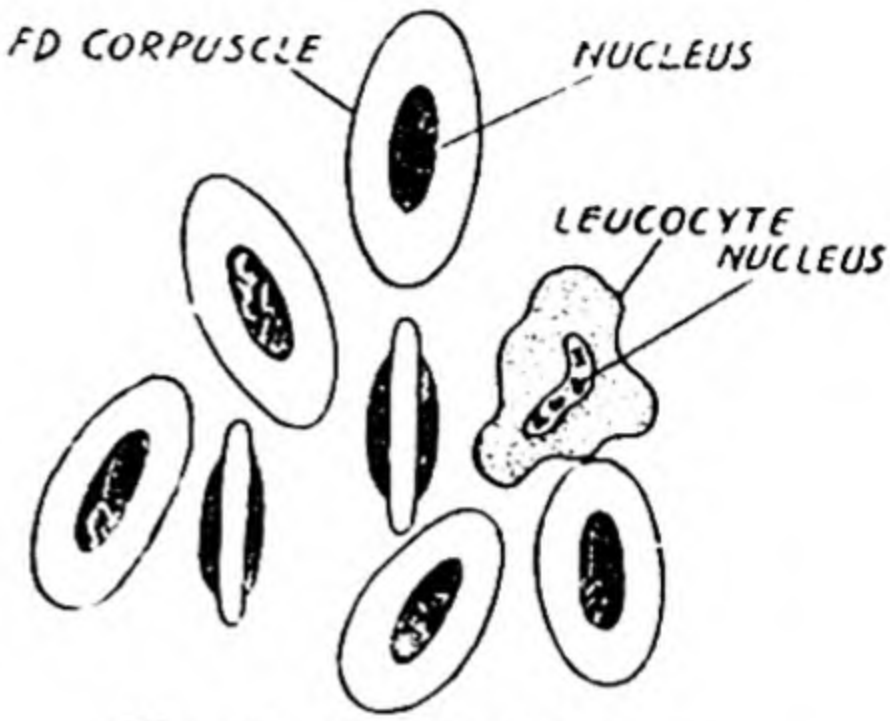

Fig. 46. Blood of the frog.

The *white corpuscles* or *leucocytes* also are nucleated but their cytoplasm is more or less colourless. Unlike the red corpuscles they can change their shape and perform creeping movements which, being similar to those of a unicellular organism known as *Amoeba*, are called *amoeboid movements*. The leucocytes can pass through the thin walls of the capillaries into the spaces between the tissue cells. They are found, therefore, not only in the blood vessels but in practically every part of the body. Their main function is to protect the body from the invasion of disease-producing bacteria and to remove waste products. They, thus, act as soldiers and scavengers.

They collect at the point of infection and engulf the bacteria and the broken down tissues. This process is known as *phagocytosis*. The leucocytes are, therefore, also known as *phagocytes*. Very often some of the leucocytes are destroyed by the bacteria in their struggle against the latter.

Functions of the Blood. The blood, perhaps, is the most important part of the animal's body. It is so vitally concerned with the activities of the organism that without it life cannot be maintained even for a short period. The instantaneous death from heart failure is a direct result of the stoppage of blood supply to the body. The functions of the blood, some of which have already been discussed, are as follows :—

(1) TRANSPORT OF OXYGEN. Oxygen is carried by the blood from the organs of respiration to the tissues of the body where it is required to carry on metabolic activities of the cells.

(2) TRANSPORT OF WASTE PRODUCTS. The blood transports carbon dioxide from the tissues of the body, where it is formed as a result of metabolic activities to the respiratory organs to be eliminated. Similarly urea, which is formed in the liver as a product of the decomposition of proteins, is carried by the blood to the kidneys where it is converted into urine and eliminated through the cloaca.

(3) TRANSPORT OF FOOD MATERIAL. The digested food material during absorption by the mucous membrane of the intestine finds its way into the blood which carries it to the tissues of the body to be assimilated.

(4) TRANSPORT OF HORMONES. Hormones or internal secretions of ductless glands directly enter the blood by diffusion when it is passing through the glands and are carried to distant regions of the body where they stimulate metabolic activities of various kinds.

(5) PROTECTION FROM DISEASE. There are many diseases which are caused by germs. They produce poisonous substances known as *toxins*, which find their way into the blood.

To neutralize their harmful effect on the body other substances, known as *anti-toxins*, are produced by the blood. The leucocytes also destroy the germs by engulfing them.

(6) EQUALIZATION OF BODY TEMPERATURE. More heat is produced in those parts of the body where metabolic or muscular activity is going on than in others. Similarly the external heat or cold affects the superficial parts of the body more than the deeper ones. When the blood circulates through the body it distributes the heat in such a way that the temperature of the various parts becomes equalized.

The Lymphatic System. We have already learnt that a part of the blood, containing digested food and oxygen, passes out through the thin walls of the capillaries and delivers these substances to the tissue-cells, and takes up waste products from them. This fluid part of the blood is known as *lymph*. It contains some white corpuscles but no red corpuscles. Lymph, thus, is practically blood without the red corpuscles.

The lymph is contained within certain vessels and cavities which constitute the *lymphatic system*. The *lymphatic vessels* are delicate branching tubes formed by the union of *lymph capillaries* which are everywhere interwoven with blood capillaries with which they have, however, no direct connection. The lymph which oozes out from the blood capillaries is collected by the lymph capillaries and passed on to the lymphatic vessels and thence to the *lymph spaces* or *sinuses*, such as the sub-cutaneous lymph spaces under the skin and the sub-vertebral lymph sinus below the vertebral column. The lymph sinuses communicate in turn with two pairs of thin-walled contractile *lymph hearts*. The *anterior hearts* lie on the sides of the vertebral column just behind the transverse processes of the third vertebra, and the *posterior hearts* one on either side of the tip of the urostyle. The former pump the lymph into the sub-scapular veins and the latter into the femoral veins. The openings of the hearts into the veins are guarded by semi-lunar valves to prevent the

lymph from flowing back into the hearts when the latter are relaxing. There are, however, no valves at the openings through

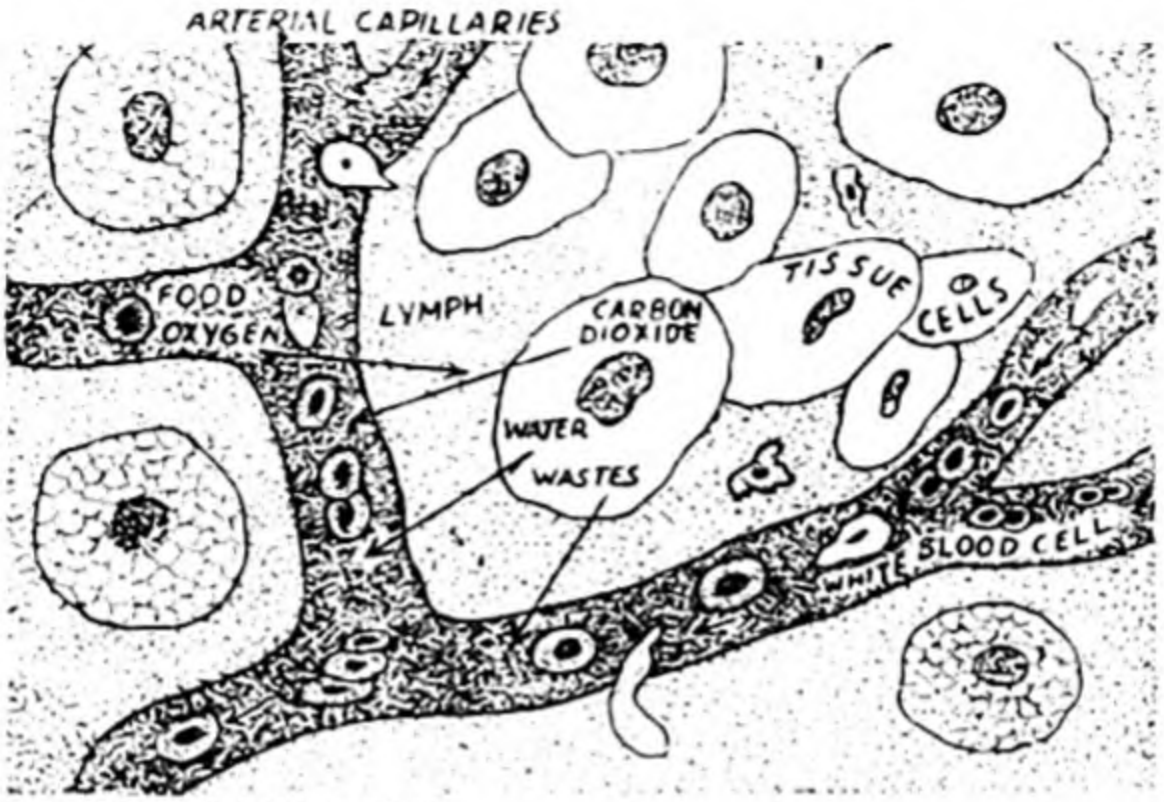

Fig. 47. Capillaries, lymph and tissue cells.

which lymph enters the hearts from the lymph sinuses. The coelom also is a large lymph sinus which communicates with the renal veins through microscopic apertures in the wall of the kidney, known as *nephrostomes*. Lymphatic vessels found in the wall of the intestine to absorb digested fats are known as *lacteals*. They contain a milky fluid which is discharged into the venous system. We, thus, see that the lymph which leaves the vascular system through the thin walls of the blood capillaries is finally returned to it through various veins. The lymphatic system, therefore, is a part of the vascular system.

CHAPTER XII

THE FROG (*continued*)

THE NERVOUS SYSTEM

The frog is often compared to a steam engine as in both of them fuel is burnt, either as food or coal, energy is released and some waste products are formed. There is, however, an obvious difference between the two. Whereas the movements of the steam engine are controlled by the engine driver, the activities of the frog are controlled by the frog itself. This function of controlling and co-ordinating of life activities is performed by the nervous system. As has been mentioned in an earlier chapter, the nervous system works like a telegraph system. As telegraphic messages can be sent from one place to another so can impulses be transmitted from one part of the body to another through the nervous system. In this way co-ordination of movements in different parts of the body and unified behaviour by the animal are rendered possible. The nervous impulses are not altogether lost once they arise but leave impressions behind which are generally referred to as experiences and which serve to guide the animal to suitably meet new situations. They, in fact, form the basis of intelligence, a faculty not so well developed in the frog.

Parts of the Nervous System. The nervous system of the frog may be divided into two parts : the *central nervous system*, consisting of the brain and the spinal cord, and the *peripheral nervous system* consisting of the nerves which connect the central nervous system with various parts of the body. These may be further divided into, (1) *cerebral nerves*, arising from the brain, (2) *spinal nerves*, arising from the spinal cord, and, (3) *sympathetic nerves*. According to their nature nerves have been

classified as (1) *sensory nerves* which convey sensory impulses of touch. sight, hearing, smell and taste from the organs concerned to the central nervous system, and (2) *motor nerves* which convey motor impulses or impulses of motion from the central nervous system to the muscles. Certain nerves contain both sensory and motor nerve fibres. They are known as *mixed nerves*.

THE CENTRAL NERVOUS SYSTEM

Spinal Cord. The spinal cord is roughly cylindrical in shape and lies in the neural canal of the vertebral column. It is continuous in front with the brain while behind it tapers to a slender filament, the *filum terminale*, which lies in the urostyle. The spinal cord is slightly enlarged opposite the fore- and hind-limbs to form the *brachial* and the *sciatic swellings* respectively. Running longitudinally in the middle of the dorsal

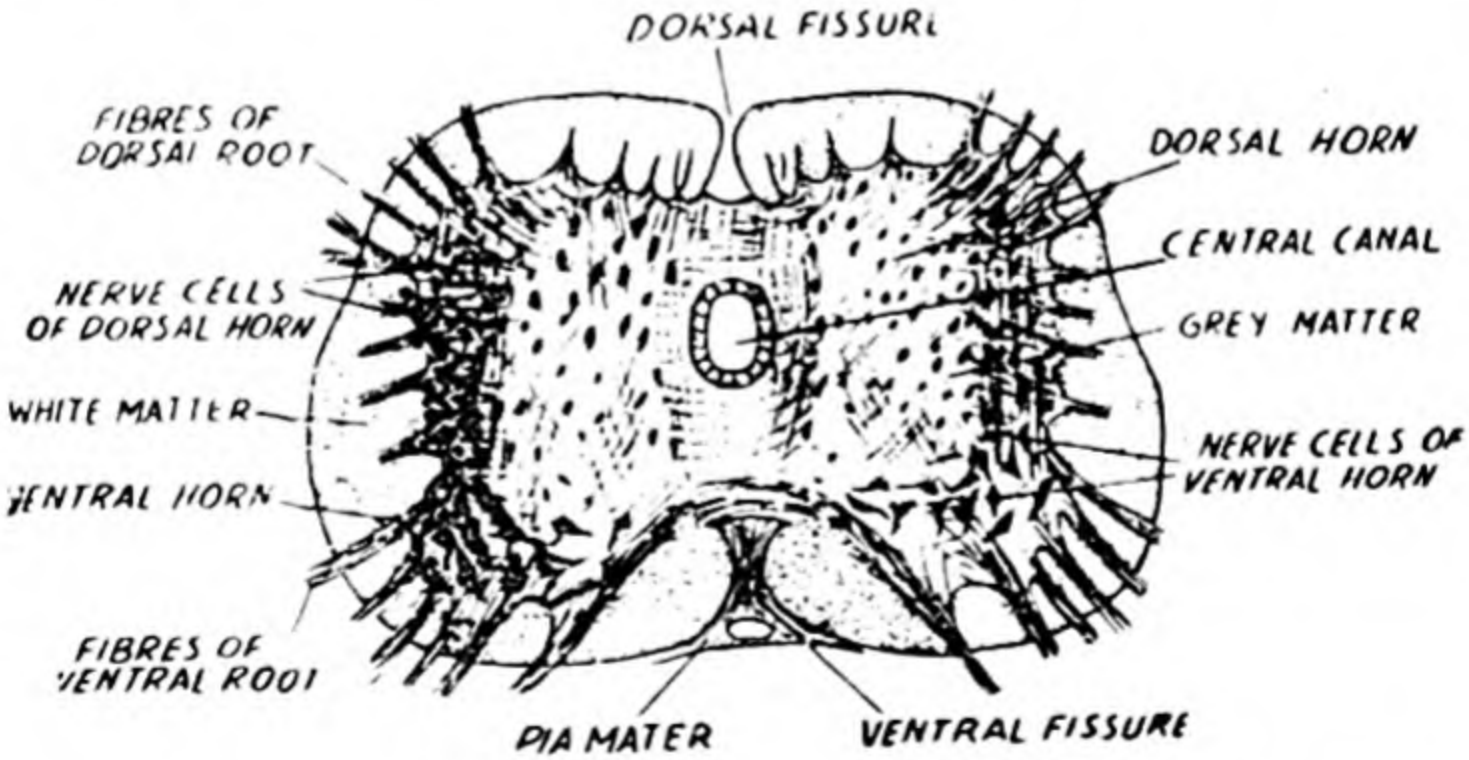

Fig. 48. Transverse section of the spinal cord of a frog.

surface of the cord is a delicate line, the *dorsal fissure*, while along the middle of the ventral surface is a distinct groove, the *ventral fissure*. The spinal cord is covered by a thin pigmented

membrane, the *pia mater* and the neural canal is lined by a thick and tough membrane, the *dura mater*. The intervening space is filled by a lymphatic *arachnoid fluid* which serves to protect the cord from shocks.

A transverse section of the spinal cord (Fig. 48), when examined under the microscope, reveals that it contains a longitudinal cavity, the *central canal*, running along its axis and lined by a layer of epithelial cells.

The central canal is continuous in front with the cavities of the brain but ends blindly behind. The section also shows that the cord is made up of two kinds of nervous tissue, the *grey matter* on the inner side immediately surrounding the canal and the *white matter* on the outer side. The grey matter is squarish in outline and is produced at the edges into *dorsal* and *ventral horns*. The grey matter consists chiefly of nerve cells while the white matter is made up largely of nerve fibres.

Brain. The brain (Figs. 49—51) forms the anterior portion of the central nervous system and lies in the cranial cavity in continuation with the spinal cord without any line of demarcation. It is hollow from inside and its cavities or *ventricles* are continuous behind with the central canal of the spinal cord. The brain, like the spinal cord, is covered with pia mater and the cranial cavity, like the neural canal of the vertebral column, is lined by dura mater. The space between the two membranes is filled with a lymphatic fluid which serves to absorb the shocks to the brain.

The brain consists of several distinct parts. The hindermost part, which is continuous behind with the spinal cord, is triangular in outline and is known as the *medulla oblongata*. Its cavity is called the *fourth ventricle*, which is covered dorsally not by nervous tissue, but by a highly vascular membrane the *posterior choroid plexus*, formed by the thickening and folding of the pia mater. In front of the medulla and roofing over the anterior part of the fourth ventricle is a transverse band of

nervous tissue known as the *cerebellum*. Anterior to it, on the dorsal side of the brain, is a pair of prominent rounded

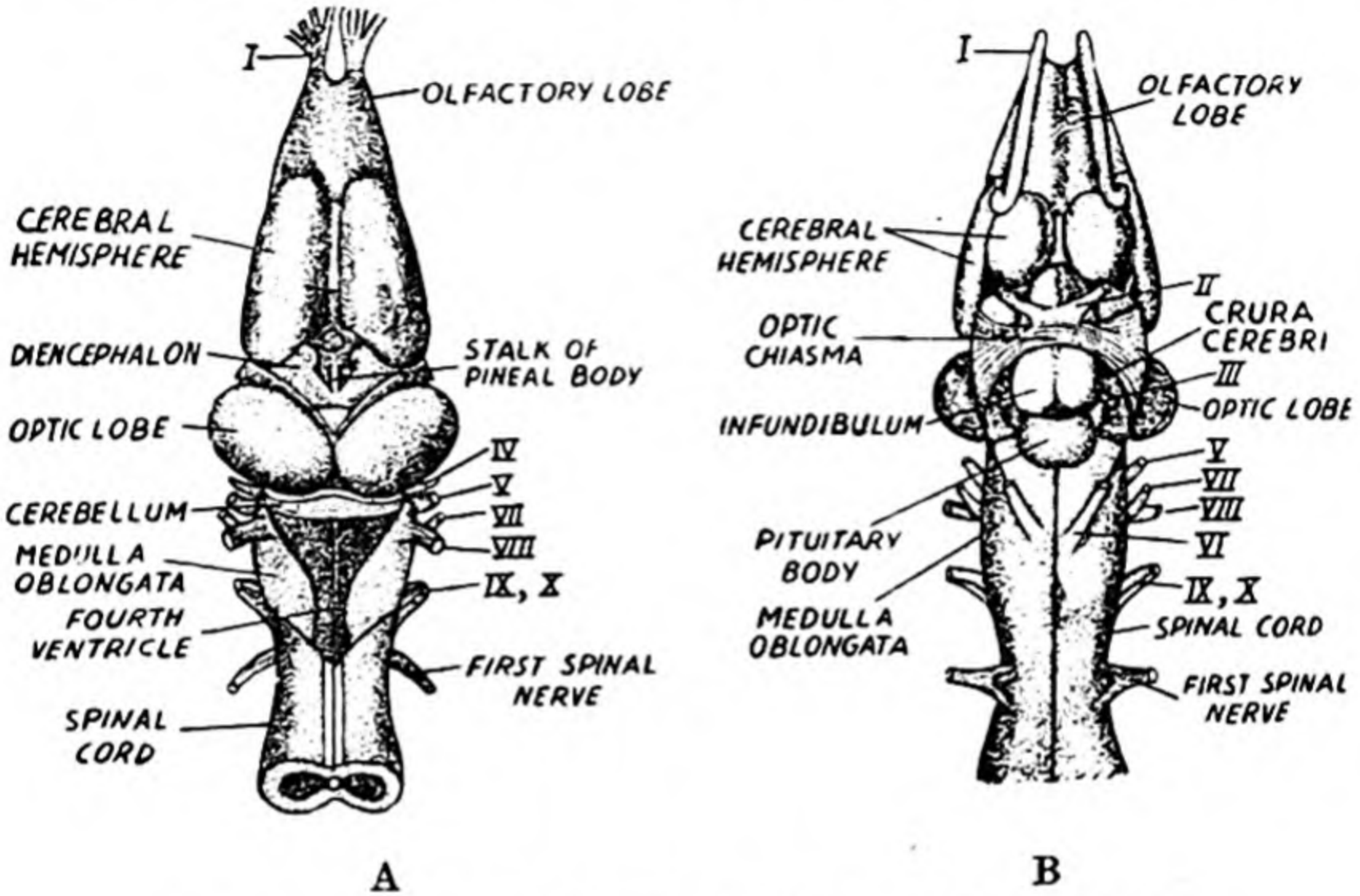

Fig. 49. Brain of the frog, A, dorsal view ; B, ventral view

bodies, the *optic lobes*, each containing a cavity, the *optic ventricle*. The two optic ventricles communicate with a central narrow passage, the *iter*, which connects the third ventricle in front with the fourtn ventricle behind. Extending from the medulla to the cerebral hemispheres and lying below the optic lobes, is a pair of white columns of nervous matter, known as the *crura cerebri*. Just in front of the optic lobes is the *diencephalon* or *thalamencephalon*, whose cavity is known as the *third ventricle*. The sides of the diencephalon are thickened to form the *optic thalami*. Its roof is covered by a vascular thickening of the pia mater, known as the *anterior choroid plexus*. Behind the plexus is a delicate process, the *pineal*

stalk, which in the tadpole bears at its tip a gland-like structure, the *pineal body*. During the course of development

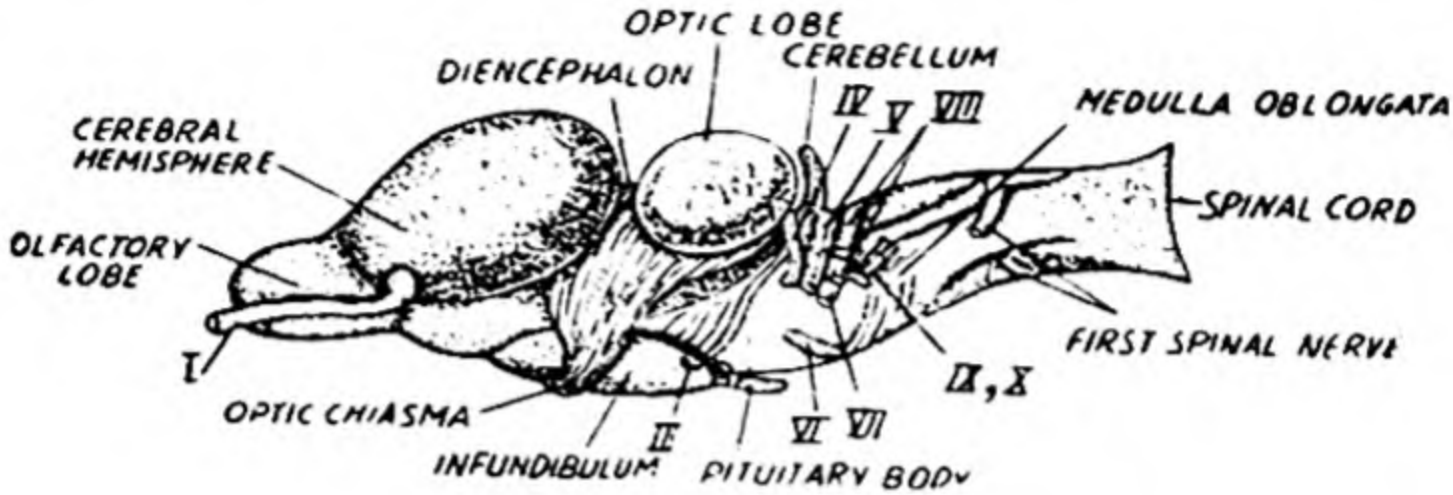

Fig. 50. Brain of the frog. A, lateral view; B, longitudinal vertical section.

the pineal body becomes detached from the stalk and comes to lie outside the skull but below the skin as the *brow spot*. On the ventral side of the diencephalon is the *optic chiasma* formed by the crossing of the optic nerves going to the eyes. Behind the optic chiasma the floor of the diencephalon

is depressed to form a bilobed structure, the *infundibulum*, containing a cavity which is continuous with the third ventricle. Attached to the hinder part of the infundibulum is a flattened ovoid sac, the *pituitary body*. It is generally left behind in the skull when the brain is removed. In front of the diencephalon is a pair of smooth ovoid bodies, the *cerebral hemispheres*, each of which contains a cavity, the *lateral ventricle*. The two lateral ventricles communicate with the third ventricle through a common median aperture, the *foramen of Monro*. The cerebral hemispheres are produced in front into two *olfactory lobes* which are fused together into a single mass but contain two distinct cavities, the *olfactory ventricles*, which are continuous with the lateral ventricles.

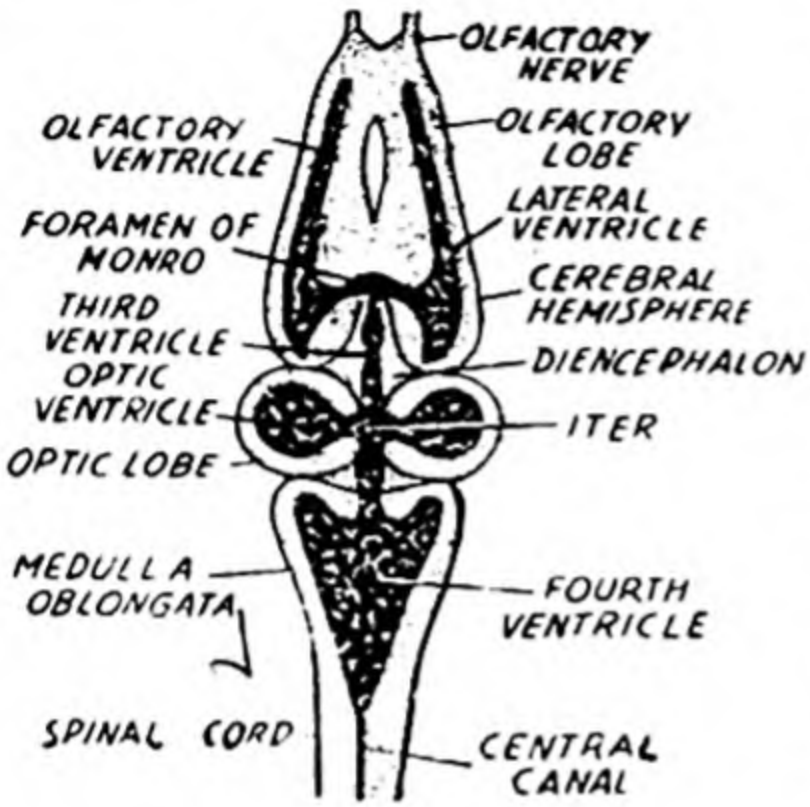

Fig. 51. Horizontal section through the brain of the frog.

The brain, like the spinal cord, is made up of both grey and white matter but their arrangement is not uniform. In the medulla oblongata and the optic lobes the grey matter is mainly internal and the white matter external while in the diencephalon, cerebral hemispheres and the olfactory lobes the white matter is internal and the grey matter forms a thin outer covering or *cortex*.

Functions of the Brain. The functions of the different parts of the brain have been determined by removing one or more parts from the brain of a living frog and watching its behaviour after the immediate effects of the injury have sub-

sided. It has been found that the olfactory lobes are concerned with the sense of smell. The cerebral hemispheres are the seat of intelligence and voluntary control. In the frog they are of comparatively small size and their surface is almost smooth. This accounts for the relatively low intelligence of the animal. In man, who is the most intelligent animal, the cerebral hemispheres form the greater part of the brain and their surface is marked with deep grooves or *sulci*. The optic lobes have an inhibiting influence on the reflex activity of the spinal cord, each lobe controlling the opposite side of the body. Their removal, therefore, makes the animal irritable. They also seem to be concerned with the sense of sight. The cerebellum is the centre of co-ordinated locomotion and equilibrium. Its extremely poor development in the frog may be explained by the fact that the animal in its normal squatting position is very stable and needs practically no balancing. The medulla oblongata controls most of the bodily activities. If all parts of the brain, except the medulla, are removed, the frog still leaps and swims, captures and swallows food, croaks and breathes normally. Removal or a serious injury to the medulla results in the death of the animal.

THE PERIPHERAL NERVOUS SYSTEM

Spinal Nerves. There are nine or ten pairs of spinal nerves in the frog. They arise from the sides of the spinal cord and pass out from the neural canal through the intervertebral foramina between the successive vertebrae. The nerves at the point of emergence are covered with white calcareous bodies, the *perigangliomic glands*. Each spinal nerve arises from the spinal cord by two roots, the *dorsal* and the *ventral* which originate from the dorsal and the ventral horns of the grey matter (Fig. 52). The dorsal root bears a swelling or *ganglion*. The two roots unite just outside the vertebral column. The nerve thus formed divides immediately into a small *dorsal*

branch and a large *ventral branch*. The dorsal branches innervate the skin and muscles of the back while the ventral branches

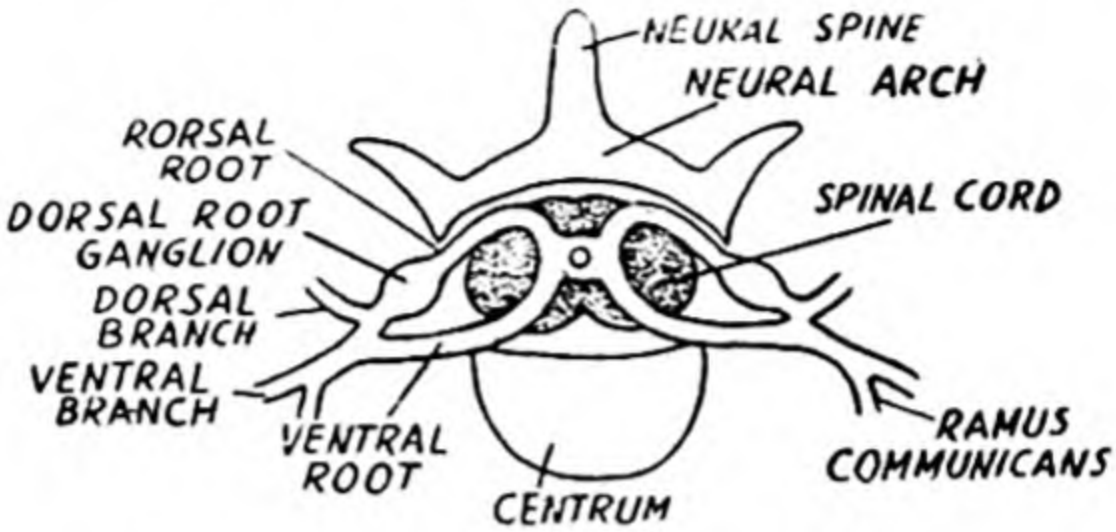

Fig. 52. Transverse section through the vertebral column of the frog to show the origin of a spinal nerve.

are distributed to the skin and muscles of the ventral side and some of them to other parts of the body also, particularly the limbs. The ventral branches, being larger, are usually called the *spinal nerves*.

The first spinal nerve or the *hypoglossal* leaves the neural canal between the first and the second vertebrae. It runs downward and forward to supply the muscles of the tongue and the floor of the mouth. The second is a very large nerve and arises between the second and the third vertebrae. It is soon joined by the small third spinal nerve, coming out between the third and fourth vertebrae, and a branch from the first, to form a network or *plexus*, the *brachial plexus*, which is continued into the fore-limb as the *brachial nerve*. The fourth, fifth and sixth nerves emerge between the fourth and fifth, fifth and sixth and sixth and seventh vertebrae respectively. They are all small nerves and supply the muscles and skin of the body-wall. The seventh, eighth and ninth nerves leave the neural canal between the seventh and eighth vertebrae, eighth and ninth vertebrae and the ninth vertebra and the urostyle respectively. They are large nerves and passing backwards are united with one another

by branches to form the *sciatic plexus*, from which arise a number of nerves. The largest of these is the *sciatic nerve* which runs along the back of the thigh and innervates the muscles and skin of the hind-limb. The roots of the seventh, eighth and ninth nerves run backward for some distance within the neural canal before coming out. They, together with the filum terminale, form a structure resembling somewhat a horse's tail. It is, therefore, known as the *cauda equina*. The tenth nerve or the *coccygeal* is a very small nerve which comes out through an aperture in the side of the urostyle. In *Rana tigrina* it is generally absent or is present only on one side.

It should be noted that the first spinal nerve supplies the muscles only and is, therefore, a motor nerve. All the others supply the muscles as well as the skin and contain both sensory and motor fibres. They are, thus mixed nerves.

Cerebral Nerves. Those nerves which arise from the brain are known as *cerebral* or *cranial nerves*. They pass out from the cranial cavity through apertures or *foramina* in the wall of the cranium and, in general, innervate the sense-organs and other parts of the head. There are ten pairs of cerebral nerves in the frog. Some of them are purely sensory, other purely motor and still others mixed.

The *first* or *olfactory nerve*, of either side, arises from the anterior end of the olfactory lobe and passing through a foramen in the transverse partition of the sphenethmoid is distributed to the mucous membrane lining the nasal chamber. It conveys the impulse of smell to the brain and is a purely sensory nerve.

The *second* or *optic nerve* is the nerve of sight. It is a large nerve arising from the side of the diencephalon. It crosses the nerve of the other side on the ventral surface of the brain. The X-shaped structure thus formed is known as the *optic chiasma* The crossing of nerve fibres at the chiasma, however, is not complete as some fibres remain on their own sides. Each nerve

then runs forward and outward to the eye of the other side. After leaving the cranial cavity through the optic foramen the nerve spreads out over the lining membrane of the eye-ball, known as the *retina*, which is the real organ of sight.

The *third* or *oculomotor nerve* is a small nerve. It arises from the crura cerebri beneath the optic lobe. It emerges from the skull through a small foramen behind the optic foramen and innervates four out of the six muscles moving the eye-ball, namely, the *inferior oblique*, *internal rectus*, *superior rectus* and *inferior rectus* (Fig. 53). It is an exclusively motor nerve.

The *fourth* or *pathetic nerve* is a very slender nerve. It arises from the dorsal surface of the brain between the optic lobe and the cerebellum and leaves the skull above the third nerve. It supplies the *superior oblique muscle* of the eye-ball, and is purely motor.

The *fifth* or *trigeminal nerve* is one of the largest of the cerebral nerves. It arises from the side of the anterior end of the medulla and, before leaving the cranial cavity through a large aperture in the pro-otic bone, is dilated into a large swelling, the *Gasserian ganglion*. As its name implies the trigeminal divides into three main branches, namely, the *ophthalmic branch* going to the skin of the snout, the *maxillary branch* to the upper jew and the *mandibular branch* to the lower jaw. The trigeminal is a mixed nerve.

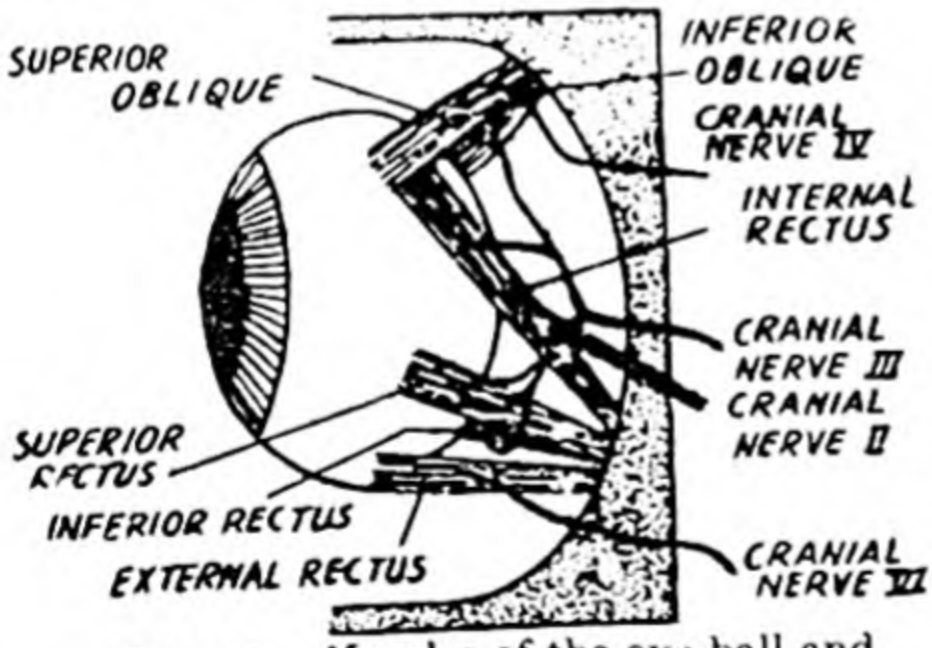

Fig. 53. Muscles of the eye-ball and their nerve supply.

The *sixth* or *abducent nerve* arises from the ventral surface

of the medulla close to the median line. It comes out of the cranium through the same aperture as the fifth, and supplies the *external rectus muscle* of the eye-ball. It is a purely motor nerve.

The *seventh* or *facial nerve* arises from the side of the medulla closely behind the origin of the fifth nerve and runs

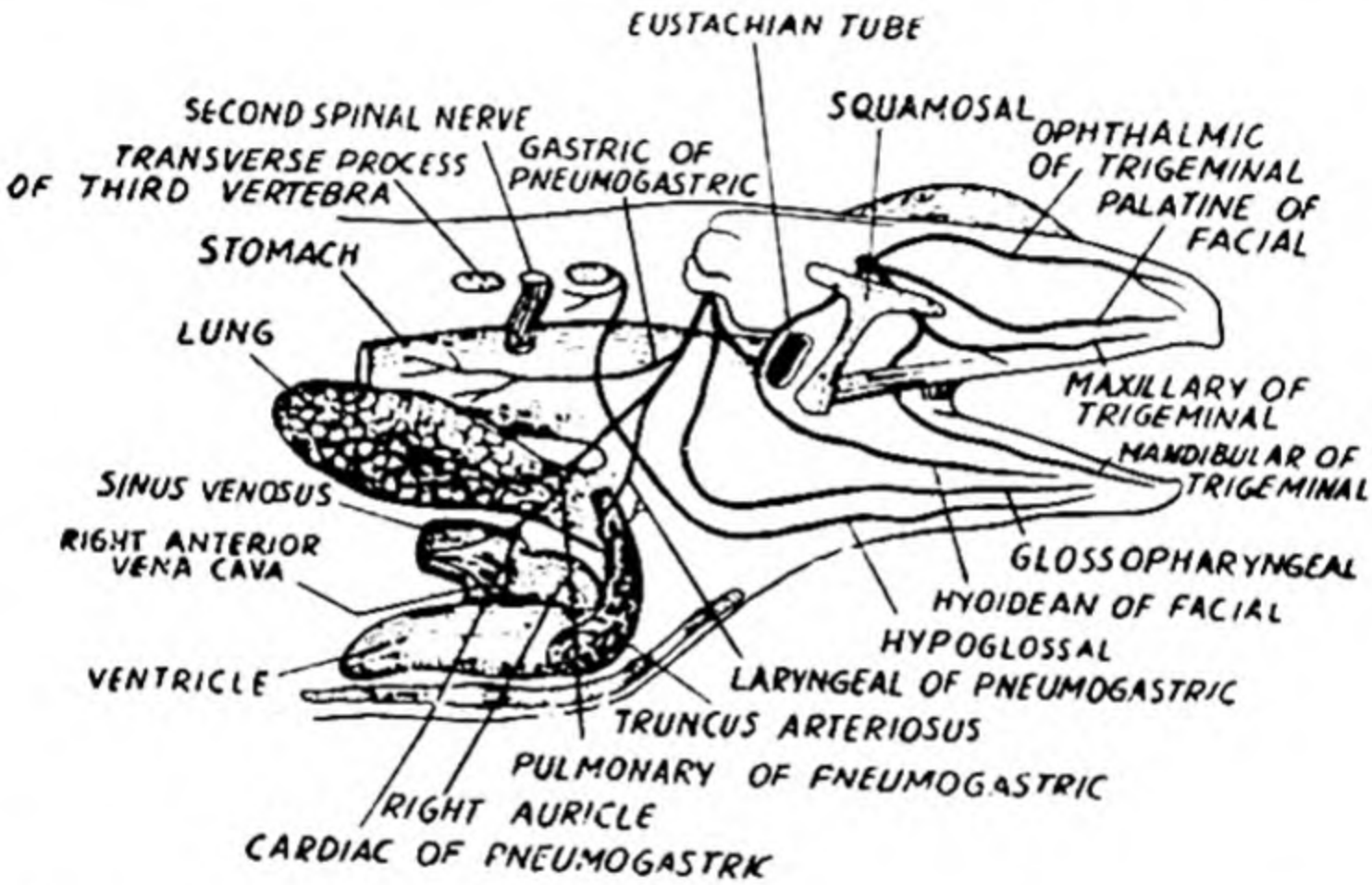

Fig. 54. Distribution of the fifth, seventh, ninth and tenth cerebral nerves of the frog. (After Marshall).

forward to unite with the Gasserian ganglion. After this it leaves the skull by the same aperture as the fifth and sixth nerves and soon divides into two branches. The dorsal or the *palatine branch* supplies the mucous membrane of the roof of the buccal cavity while the ventral or the *hyomandibular branch* is distributed to the muscles and skin of the lower jaw and muscles of the hyoid. The facial is a mixed nerve.

The *eighth* or *auditory nerve* is the nerve of hearing. It arises from the side of the medulla immediately behind, and

touching the root of the seventh nerve. It enters the auditory capsule through an aperture in its inner wall and is distributed to the internal ear. It is a purely sensory nerve.

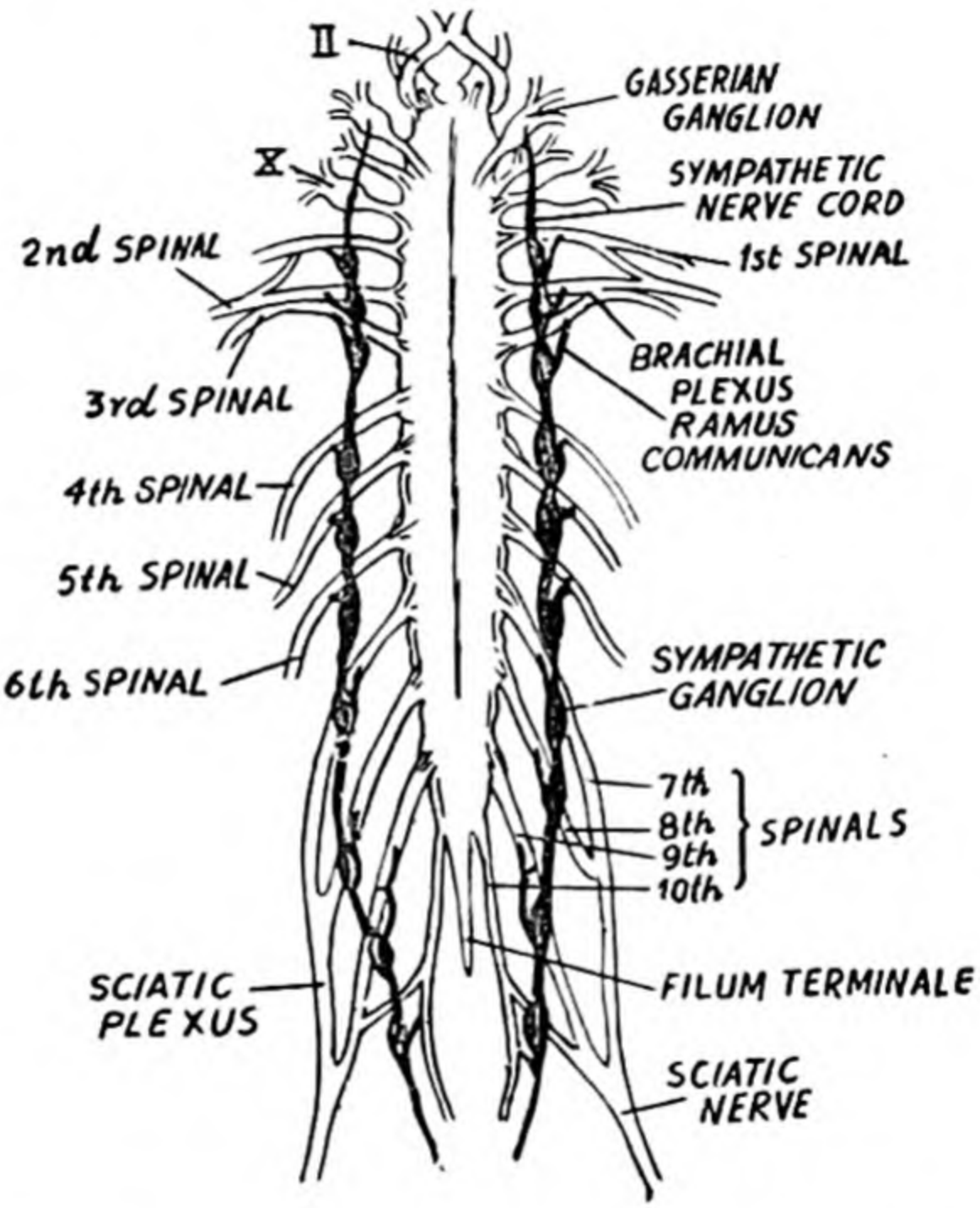

Fig. 55. Spinal nerves and the sympathetic nervous system of the frog, ventral view. (After Wheeler).

The *ninth* or *glossopharyngeal nerve* arises from the side of the medulla behind the eighth nerve and leaves the cranial cavity through an aperture on the outer side of the occipital condyle. After sending a branch to join the hyomandibular

division of the facial nerve it runs downward and forward to supply the mucous membrane of the tongue and pharynx, and muscles of the hyoid. It is a mixed nerve.

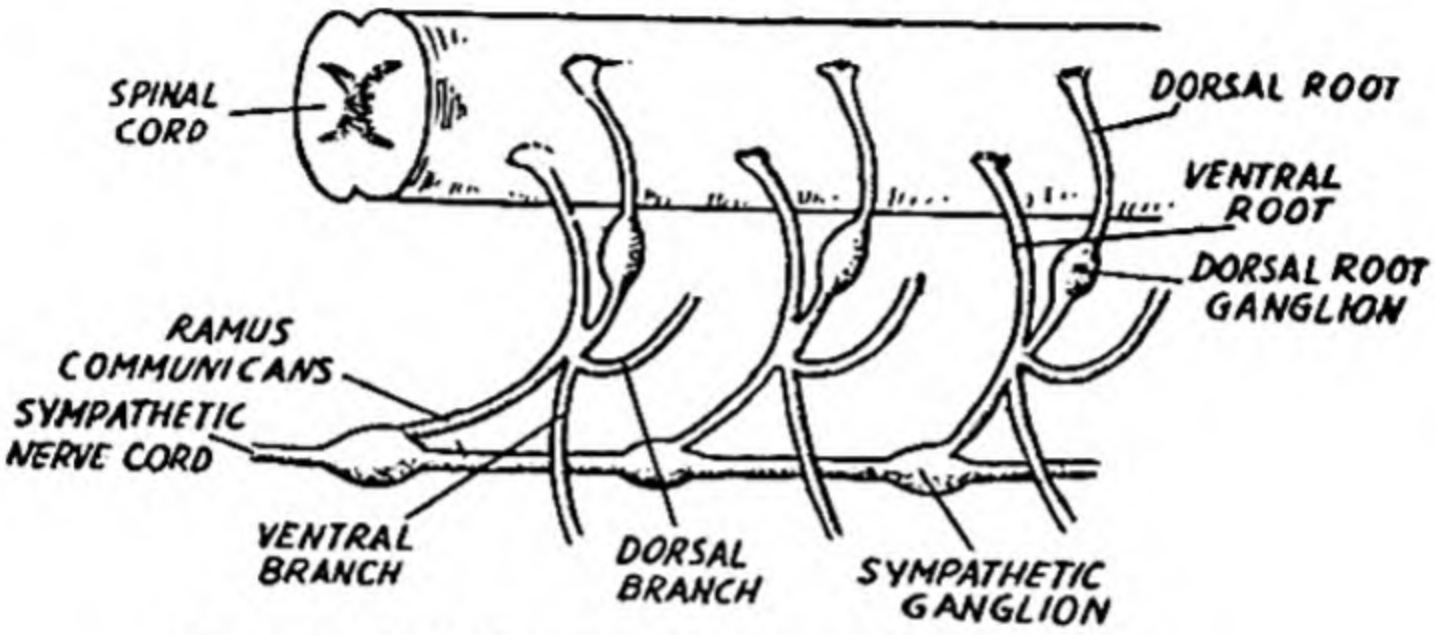

Fig. 56. Relationship of the sympathetic cord to the spinal nerves in the frog.

The *tenth* or *vagus nerve* is a large nerve. It arises in common with, and leaves the skull by the same aperture as, the ninth. Just outside the skull it expands into the *vagus ganglion*. It has a wide distribution, being the only cerebral nerve to extend behind the head. It applies the larynx. heart, lung and stomach. It is, therefore, also known as the *pneumogastric nerve*. It is a mixed nerve.

Sympathetic Nervous System. The sympathetic nervous system (Fig. 55) consists of a pair of delicate *sympatheti ccords* lying one on either side of the dorsal aorta and continued forward along the outer sides of the systemio arches. Towards the anterior end each cord enters the skull through the vagus foramen and ultimately terminates in the Gasserian ganglion. Each cord bears, at intervals, nine or ten small ganglia, each of which is connected with the corresponding spinal nerve by a branch, the *ramus communicans* (Fig. 56). The sympathetic ganglia give off nerves to the heart and blood vessels, stomach, liver, intestine, kidneys, gonads and the urinary bladder.

Reflex Action. If a frog, whose brain has been destroyed, is hung up with the legs pointing downwards and one of the toes is pinched with a pair of forceps or touched with weak acetic acid the corresponding foot will be drawn up to avoid the irritation. As the brain is absent the action of the frog is not brought about by the exercise of free will. An action of this kind is known as a *reflex action* which may be defined as *an automatic response to a stimulus without the intervention of the will.* Reflex actions are spontaneous and mechanical, that is, a particular stimulus always produces the same response without any choice on the part of the animal. Actions which are performed by the will of the animal as a result of free choice are known as *voluntary actions.*

It is not necessary to destroy the brain in order to bring about a reflex action. We perform numerous reflex actions in our daily life. We at once close our eyes if strong light is suddenly flashed on them or withdraw our hand if it accidentaly happens to touch some hot object. Certain actions which in the beginning are controlled by the will become, in the course of time, reflex actions. For instance, we can go on walking in a normal manner even while we are absorbed in a serious discussion and are not paying any attention to walking. All these reflex actions, though not performed by the will, are within our knowledge. There are certain reflex actions, such as the flow of bile from the gall-bladder when the food reaches the duodenum which take place even without our knowledge.

Let us now see how a reflex action is produced. When a toe of the frog, in the experiment described above, is pinched the impulse produced by the stimulus is carried from the skin to the spinal cord by a spinal nerve through the dorsal root which is sensory in nature. The spinal cord then sends an impulse to the muscles of the leg through the ventral root of the spinal nerve, which consists of motor fibres. As a result of this the muscles contract and the foot is withdrawn. The

nerve bringing the impulse from the point of stimulus to the central nervous system is known as an *afferent nerve* and that

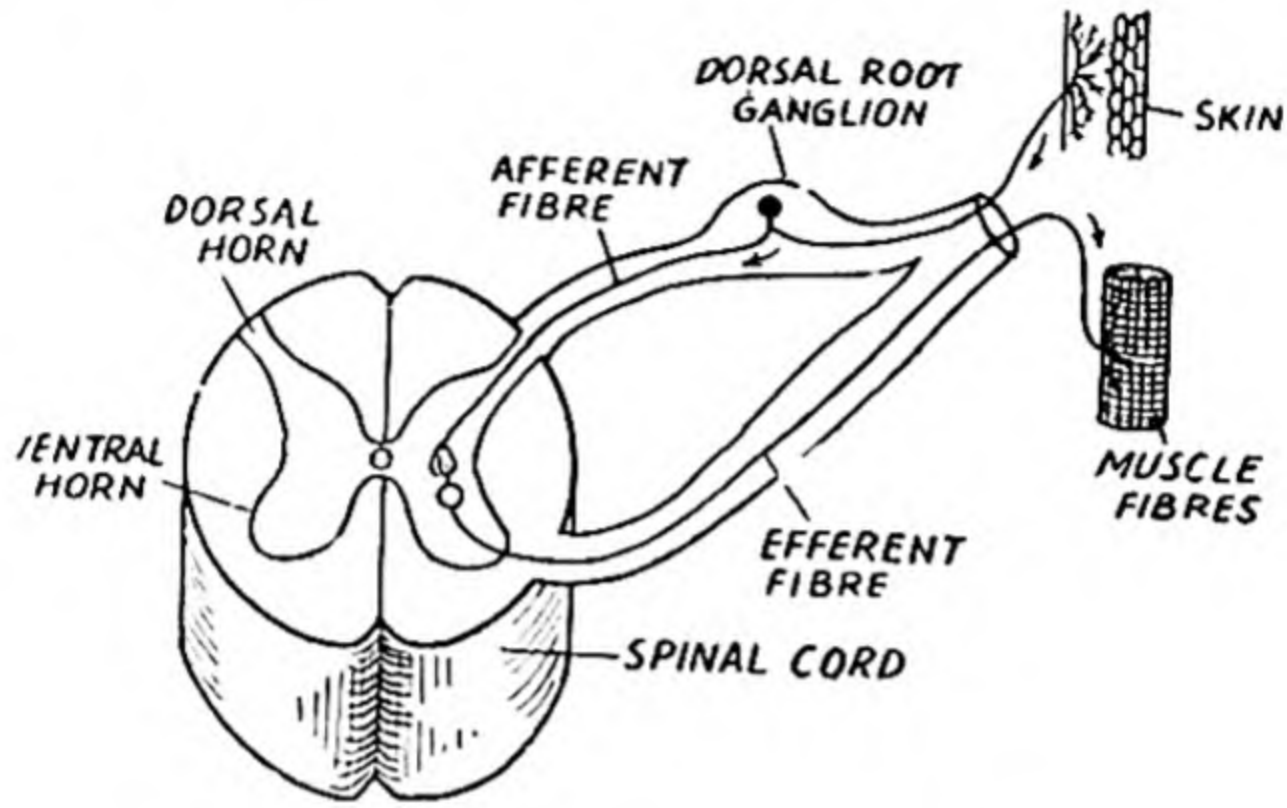

Fig. 57. Diagram to illustrate a reflex arc.

taking the impulse from the central nervous system to the muscles is called an *efferent nerve*. The path followed by an impulse in a reflex action is known as a *reflex arc* (Fig. 57). A reflex arc, thus, consists of (1) an afferent nerve, (2) a part of the central nervous system (brain or spinal cord) and (3) an efferent nerve.

The ability to perform reflex actions is useful to the animal in two ways. First, it avoids delay in responding to a stimulus which is harmful to the animal and calls for immediate action. That is why a stimulus far away from the brain, as pinching of a frog's toe, is not allowed to reach the brain but immediately responded to by the spinal cord. Secondly, the brain is relieved from too much strain when responses of a routine nature take the form of reflex actions. If, for example, we were to exercise our will every time we walked or bile flowed from the gall-bladder, the brain would soon be tired

CHAPTER XIII

THE FROG (*continued*)

THE SENSE-ORGANS

There are five special senses in the frog, as in our own case, namely, those of *touch*, *smell*, *taste*, *sight* and *hearing*. All of them have their own special organs known as the *sense-organs*, which place the animal in communication with the outer world, and enable it to adjust itself to changes in its environment. The different sense-organs are specialized, that is, each is sensitive to a particular type of stimulus. Thus the organs of sight are affected only by light and those of hearing only by sound. The impulses caused by external stimuli are normally carried from the sense-organs to the brain by the sensory nerves either directly or through the spinal cord. In the brain impulses give rise to sensations by which the animal becomes aware of the stimuli acting on the sense-organs. It is, thus, clear that sense-organs by themselves cannot consciously interpret impulses caused by stimuli. This faculty is possessed only by the brain.

Organs of Touch. The *organs of touch* are lodged in the skin which is richly supplied with sensory nerve fibres. They consist of groups of flattened cells, the *tactile cells*, found below the epidermis. Each group of tactile cells constitutes a *touch corpuscle*, which is innervated by the nerve endings of a sensory nerve. Due to the presence of touch corpuscles the skin is sensitive not only to mechanical touch but also to chemical stimuli and variations in temperature and humidity.

Organs of Smell. The *organs of smell* are located in a pair of *nasal* or *olfactory sacs* which are enclosed in the olfactory capsules of the skull. The two nasal sacs are separated

from each other by a vertical partition, the *nasal septum*. Each sac communicates with the outside through the external nostril and with the buccal cavity through the internal nostril. The olfactory sacs are lined by a mucous membrane consisting of columnar epithelial cells containing special cells, known as *olfactory cells*, which are sensitive to smell. Each olfactory cell is long and narrow, and is swollen where the nucleus lies. Its outer free end bears a tuft of cilia and the inner end is drawn out into a fine thread-like process, connected with a branch of the olfactory nerve which carries the impulse of smell to the brain.

Organs of Taste. The *organs of taste* are specialized epithelial cells, the *taste-cells*, found in the mucous membrane lining the buccal cavity especially on the tongue and the region of the vomerine teeth. The taste-cells are elongated and form groups known as *taste-buds* which are innervated by the nerve endings of the glossopharyngeal nerve and the palatine branch of the facial nerve. The taste-buds of the tongue are situated on small papillæ of the mucous membrane. Contact with food stimulates the taste-buds and the impulse is carried to the brain through the nerves mentioned above.

Organs of Sight. The *organs of sight* are a pair of eyes which are lodged in cavities on the sides of the head known as *orbits*. Each eye has three eyelids which have already been described (p. 30). The main part of each eye, the *eye-ball* (Fig. 58), is more or less spherical in shape and hollow from inside. It is moved freely within the orbit by six muscles (Fig. 53). The wall of each eye-ball consists of three layers or coats, namely, *sclerotic*, *choroid* and *retina*.

The *sclerotic* is the outermost coat of the eye-ball. It is composed of fibrous connective tissue and cartilage. The exposed part of the sclerotic is transparent and is known as the *cornea*. A thin transparent epithelial layer, the *conjunctiva*.

which, in fact, is a part of the outer epithelial covering of the skin, is fused externally with the cornea and in the adult frog forms practically a part of it. The conjunctiva is continuous with the inner lining of the eyelids. It is kept moist by the secretion of a gland, the *Harderian gland*, which lies in the orbit.

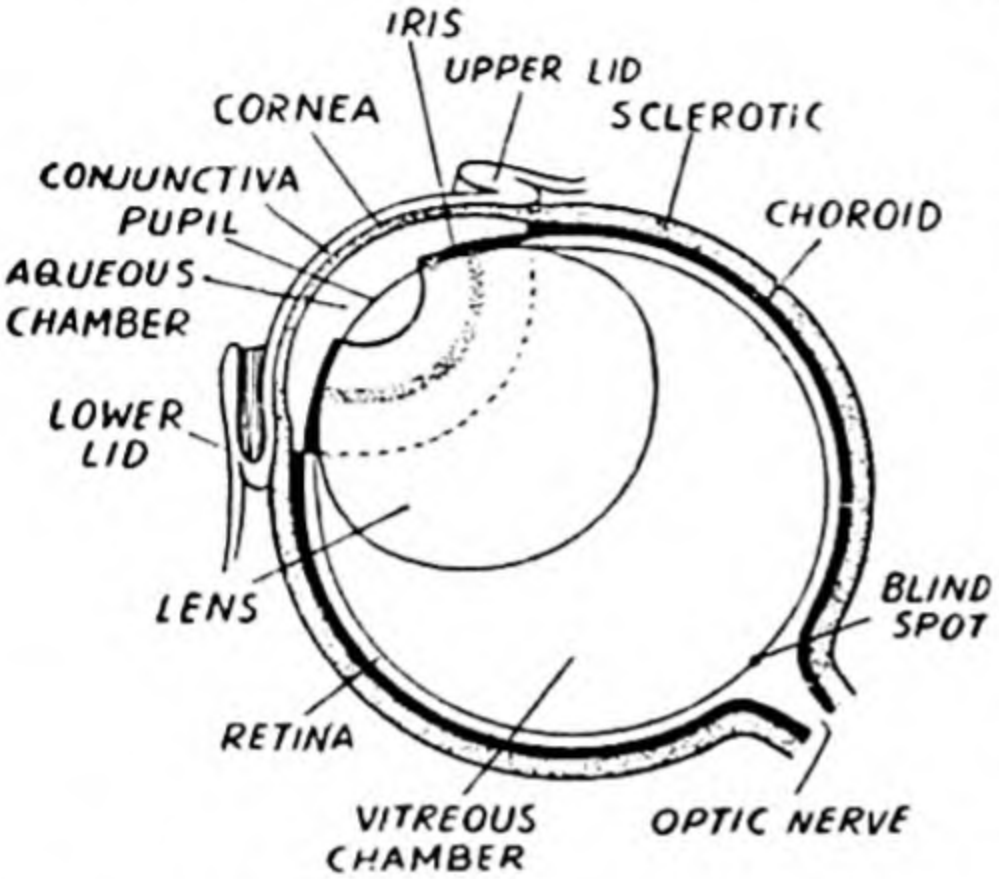

Fig. 58. A diagrammatic section through the eye of the frog.

The *choroid*, which is the middle coat of the eye-ball, is vascular and pigmented. As it enters the exposed part of the eye it bends inwards to form a partition, the *iris*, which has in the centre an opening, the *pupil*. The iris contains circular and radial unstriped muscles which control the size of the pupil. The contraction of the circular muscles reduces the size of the pupil while that of the radial muscles enlarges it. This arrangement regulates the amount of light entering the eye. The iris divides the cavity of the eye-ball into a small outer *aqueous chamber* and a large inner *vitreous chamber*. The former contains a transparent watery fluid, the *aqueous humour* and the latter is filled with a gelatinous substance, the *vitreous humour*. Just behind the iris is a transparent, more or less spherical, *lens*, enclosed in a delicate membrane, the *capsule* of the lens.

The *retina* is the innermost coat of the eye-ball and lines the vitreous chamber. It consists of an outer pigmented layer, fused with the choroid, and an inner semi-transparent membrane.

The optic nerve, after passing through the sclerotic and choroid, spreads out over the inner surface of the retina. The point of

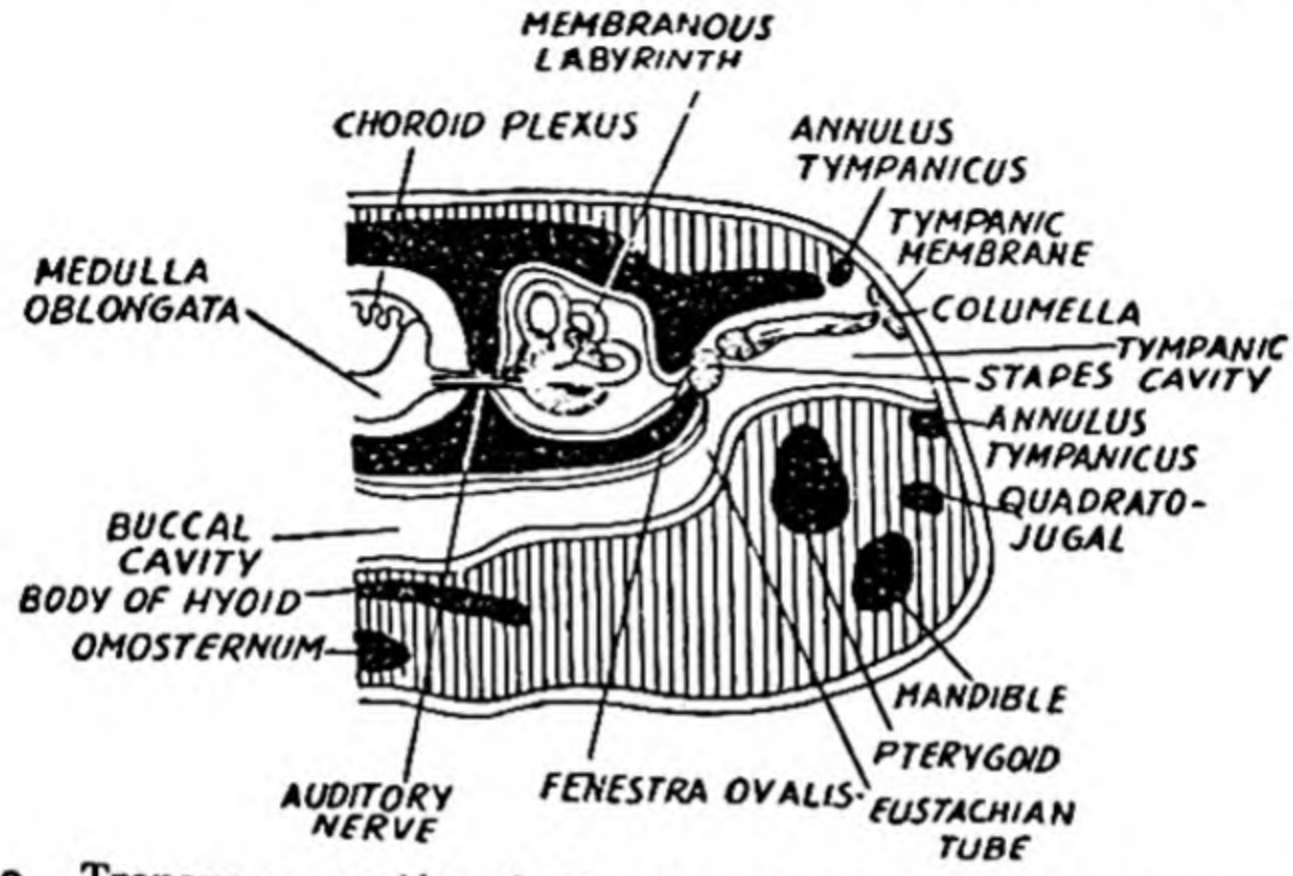

Fig. 59. Transverse section (half) through the head of a frog to show the structure of the ear (diagrammatic).

entrance of the optic nerve is known as the *blind spot*. The retina except at the blind spot, is the only part of the eye which is sensitive to light. It is, therefore, the essential organ of sight.

The eye works more or less like a photographic camera. By the help of the cornea and the lens a small inverted image of the object in front of the eye is formed on the retina and carried to the brain through the optic nerve. The eye of the frog has practically no power of accommodation, that is, it cannot adjust itself to bring into focus objects at different distances from it. Only those objects which are at a particular distance from the eye are in focus.

Organs of Hearing. The *organs of hearing* are the two ears. Each ear (Fig. 59) consists of two divisions, the *middle ear* and the *internal ear*. The middle ear is concerned with the reception of sound waves and their transmission to the internal

ear, which is the sensitive part of the ear and is, thus, the essential organ of hearing.

The *middle ear*, though externally situated, is so called besause it corresponds to the middle ear of the mammals in which there is also present an external ear, which is absent in the frog. The cavity of the middle ear, known as the *tympanic cavity*, is bounded externally by the *tympanic membrane* or *tympanum* and internally by the auditory capsule. A rod of bone and cartilage, the *columella*, is attached by one end to the inner surface of the tympanum and by the other to a small nodule of cartilage, the *stapedial plate* or *stapes*, which lies over a small aperture, the *fenestra ovalis* in the wall of the auditory capsule. Ventrally the tympanic cavity communicates with the buccal cavity through a passage, the *Eustachian tube*, which maintains equal pressure on the two faces of the tympanum.

The *internal ear* is a complicated structure, known as the *membranons labyrinth* (Fig. 60), which lies within the auditory capsule. The labyrinth consists of an irregular bag known as the *vestibule* and three *semi-circular canals*. The vestibule is divided into an upper large portion, the *utriculus* and a lower smaller portion, the *sacculus*. From the latter project backwards three small swellings which represent the *cochlea* of the rabbit. The semi-circular canals lie at right angles to one another and each opens into the utriculus at either end. Two of the semi-circular canals lie

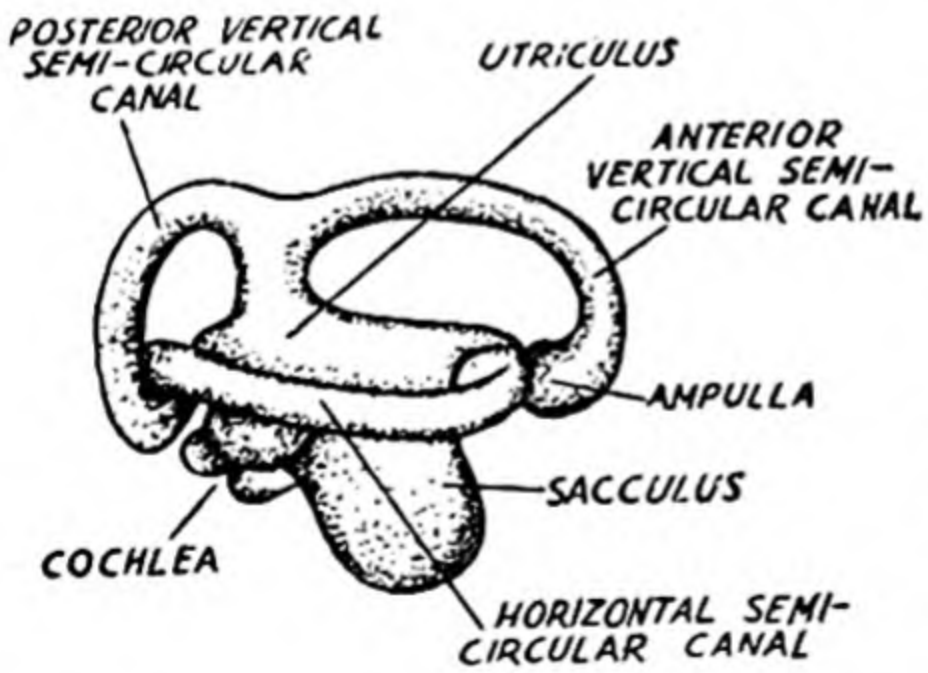

Fig. 60. The membranous labyrinth of the frog.

vertically and, according to their position, are known as the *anterior* and *posterior vertical canals*, while the third lies horizontally and is known as the *horizontal canal*. The two vertical canals are united at their adjacent ends before opening into the utriculus. One end of each semicircular canal is enlarged to form a swelling, known as an *ampulla*. The membranous labyrinth floats in a fluid. the *perilymph*, contained in the auditory capsule and its own cavity is filled with another fluid, the *endolymph*, in which are present crystalline calcareous particles, the ear-stones or *otoliths*. The labyrinth is lined with epithelium consisting of cubical cells except at certain places where they are greatly elongated and bear sensory processes, the *auditory hair*, at their free ends. A group of such cells constitutes an *acoustic spot* (Fig. 61) which is innervated by a branch of the auditory nerve. There is an acoustic spot in each ampulla, situated on a ridge, and there are a number of them in the vestibule.

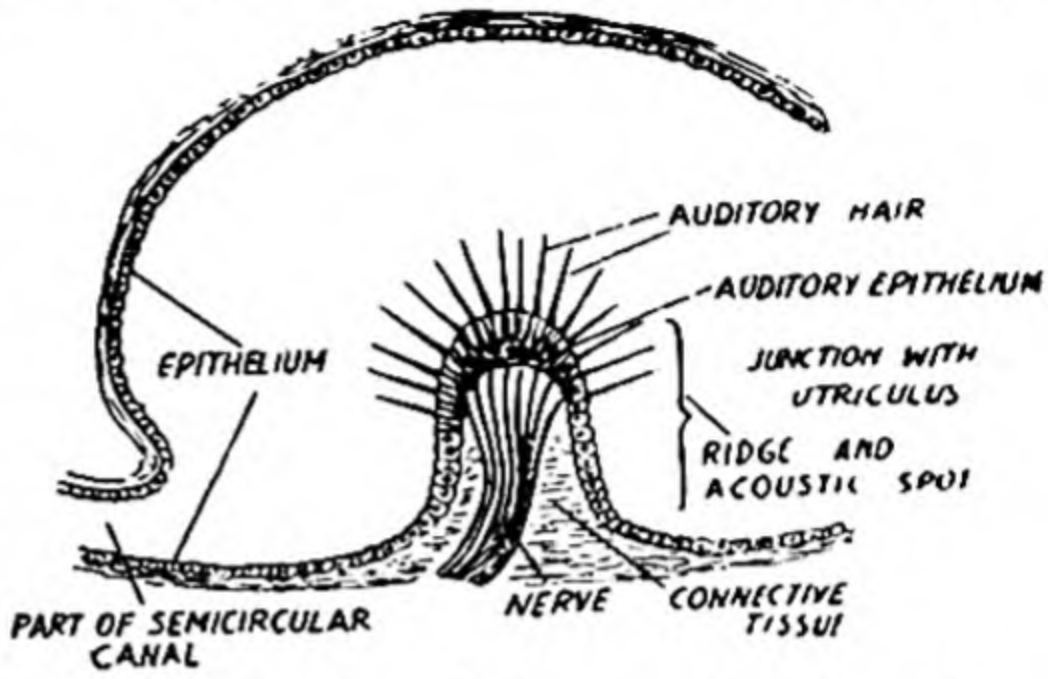

Fig. 61. Longitudinal section through an ampulla.

The membranous labyrinth serves the double function of hearing and the maintenance of equilibrium. During the act of hearing the sound waves strike the tympanum and set it into vibrations which are carried by the columella to the stapedial plate. Thence the vibrations, passing through the perilymph and the endolymph, stimulate the sensory cells of the acoustic spots by acting on the auditory hair. The impulses, thus set up, are

conveyed by the auditory nerve to the brain where they produce the sensation of sound.

The equilibrium of the body is maintained by the semi-circular canals. When the head of the frog is tilted the otoliths, due to gravity, press on the auditory hair of an acoustic spot. The impulse thus produced is carried to the brain through the auditory nerve. As the semi-circular canals are arranged in three planes and at right angles to one another, disturbance of the equilibrium in any direction stimulates one of the acoustic spots. In addition to the maintenance of equilibrium the semi-circular canals are also concerned with the sense of direction and velocity of movement.

CHAPTER XIV

THE FROG (*continued*)

THE URINOGENITAL SYSTEM

The urinogenital system, as the name indicates, consists of two systems, namely, the *urinary system* and the *genital* or *reproductive system*.

Urinary System. The urinary system is concerned with the removal of waste products, chiefly urea, from the blood by the kidneys and their elimination from the body. This process is known as *excretion* and the organs concerned as the *excretory organs*. Other excretory organs in the frog, besides the kidneys, are the lungs, skin and liver.

The kidneys are a pair of dark red flattened bodies roughly oval in shape, lying in the subvertebral lymph sinus, one on either side of the dorsal aorta. A yellowish *adrenal body* lies longitudinally on the ventral surface of each kidney. The kidney is made up of a large number of convoluted *urinary tubules*, richly supplied with blood capillaries and bound together by connective tissue. The urinary tublues filter out water and urea from the blood and pass them to the kidney duct or *ureter* which leaves the kidney at its outer border. The two ureters run backwards and open dorsally by two separate apertures into the cloaca. The *urinary bladder*, which is a thin-walled distensible bag, opens ventrally into the cloaca, more or less opposite to the openings of the ureters. The urine, formed by the combination of water and urea, is brought into the urinary bladder by the ureters and is stored there before being discharged through the cloacal aperture.

Reproductive System. Whereas all the systems hitherto described are concerned with the life of the individual animal

the reproductive system serves to perpetuate the species. In the frog the male and female reproductive organs are found in separate individuals.

The *male reproductive organs* (Fig. 62) consist of a pair of *testes* or *spermaries* and their ducts. The testes are yellow ovoid bodies, lying ventral to the kidneys. Each testis is enclosed by the peritoneum which is continued on the dorsal side to form a double fold known as the *mesorchium*, by which the testis is attached to the body-wall. The male germ cells or *spermatozoa* are formed in the testes. From the inner margin of each testis arise a number of fine ducts the *efferent ducts* or *vasa efferentia*, which run in the peritoneum and entering the kidney near its inner border open into some of the urinary tubules. The spermatic fluid or *milt* and the urine are thus both carried to the cloaca by the ureters which, therefore, are known, in the male, as the *urinogenital ducts*.

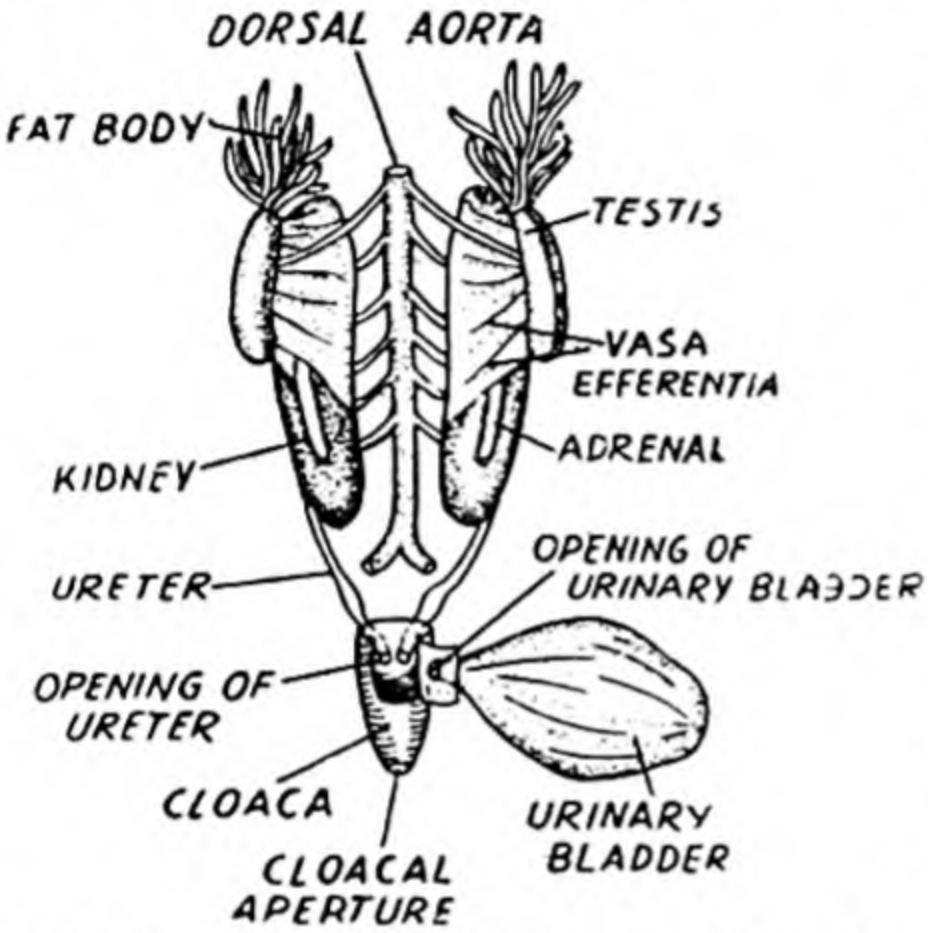

Fig. 62. Urinogenital system of the male frog, ventral view. (From Storer, slightly altered).

The *female reproductive organs* (Fig. 63) consist of a pair of *ovaries* and a pair of *oviducts*. The ovaries, like the testes. lie ventral to the kidneys. Each ovary is a lobulated hollow sac covered by the peritoneum which extends dorsally to form a double membrane, the *mesovarium*, by which the ovary is suspended from the dorsal body-wall. The ovarian blood-vessels and nerves pass between the two membranes of the mesova-

rium. During the breeding season the ovaries become distended with ripe eggs each of which is half black and half white. The oviducts are a pair of long coiled tubes lying dorsal to the ovaries and extending in front to the roots of the lungs. Here each oviduct ends in a ciliated funnel, the *ostium*, which opens into the coelom. Posteriorly each oviduct dilates into a large chamber which opens into the cloaca through its dorsal wall in front of the opening of the ureter. During the breeding season the ripe eggs are shed into the coelom by the bursting of the ovaries. The eggs float about in the coelomic fluid till they find their way into the ciliated funnels of the oviducts. The eggs are carried forward towards the funnels by the action of cilia lining the body cavity and the funnels. The eggs during their passage through the oviduct become covered, in three distinct layers, with an albuminous material or jelly, secreted by the glandular walls of the oviduct. The eggs are finally passed out through the cloacal aperture. The jelly, on coming into contact with water, swells up enormously to form the frog's *spawn*. The chief function of the jelly is to protect the eggs from mechanical injuries as well as from the attacks of bacteria, fungi and aquatic insects.

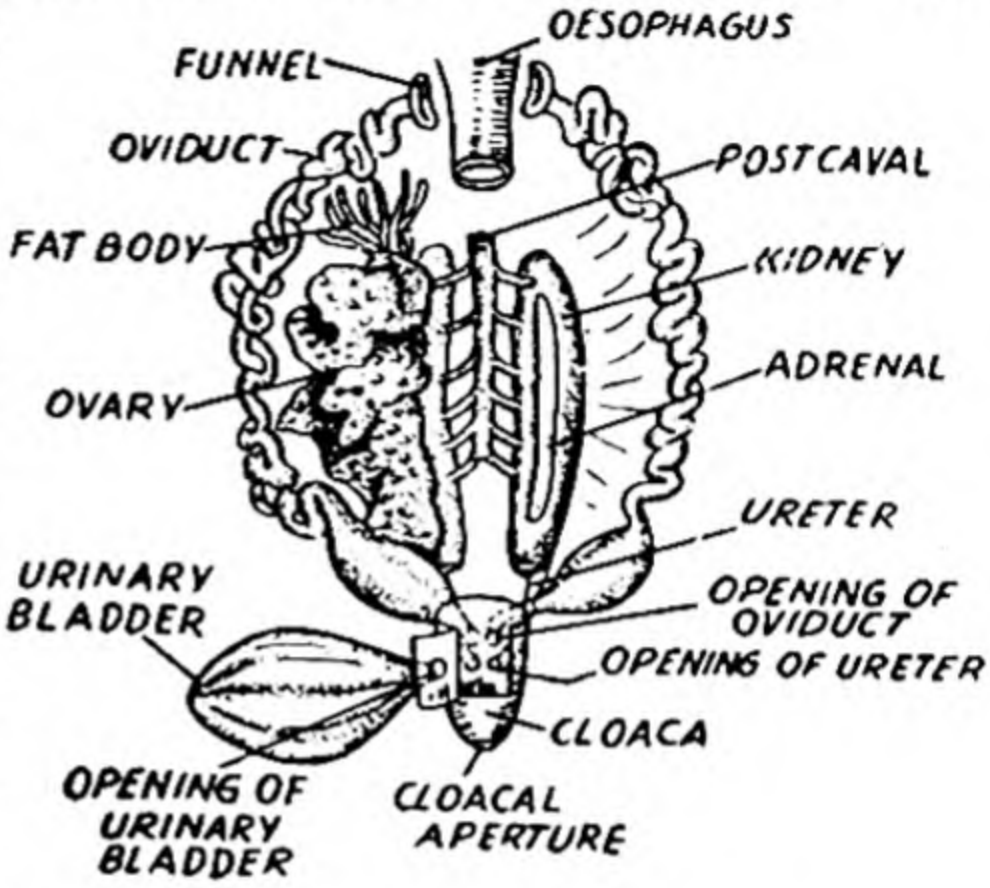

Fig. 63. Urinogenital system of the female frog, ventral view; left ovary removed. (From Storer, slightly altered).

It should be noted that in the male the ureters carry both the urine and the spermatic fluid to the cloaca whereas in the female the ureters carry only the urine and there are separate ducts (oviducts) for the transport of the eggs.

Fat Bodies. The *fat bodies* are a pair of yellowish organs attached to the anterior ends of the gonads. Each fat body bears finger-like processes which vary in number not only in different individuals but also in the same individual at different times of the year. As mentioned in a previous chapter the fat bodies are store-houses of reserve food material.

CHAPTER XV

HISTOLOGY OF THE FROG

SIMPLE TISSUES

We have already learnt that the body of an animal is made up of cells which are grouped together to form *tissues*. The study of the microscopic structure of tissues is known as *histology*. Tissues may be *simple* or *compound*. A simple tissue is formed by the grouping together of similar cells whereas a compound tissue is formed by the combination of different kinds of cells. Simple tissues are divided into four main classes, namely, *epithelial*, *muscular*, *skeletal* and *nervous*.

Epithelial Tissue. The *epithelial tissue* consists of cells converting the free surfaces of organs or lining their cavities. As there is only a small amount of intercellular substance, the cells of the epithelial tissue lie close together. There are various kinds of epithelia but only the more important ones will be described here.

The *squamous* or *pavement epithelium* (Fig. 64) consists of thin and flattened cells joined edge to edge like the tiles of a floor. Each cell contains a rounded nucleus in the centre. A sample of squamous epithelium may be easily obtained from the skin of a frog. If a living frog is kept for some time in water it will cast off the outermost layer of its skin in small pieces known as *surface castings*. Miscroscopic examination of these castings will

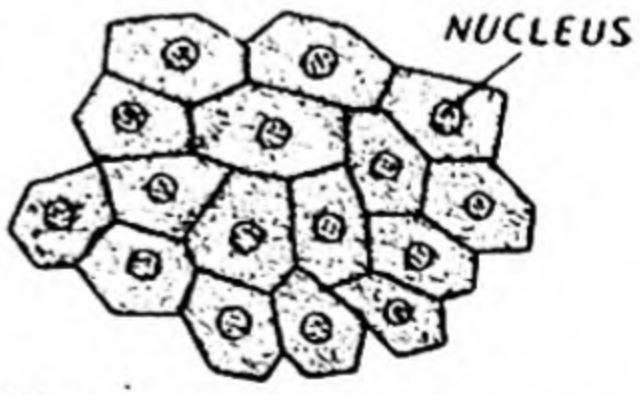

Fig. 64. Squamous epithelial cells from the frog's skin.

show that they are composed of extremely thin and broad epithelial cells.

The *columnar epithelium* (Fig. 65) is made up of elongated cells placed side by side, like columns, with their long axes perpendicular to the surface. The columnar epithelium may be obtained from the lining of the intestine of the frog. By teasing out a small piece from the mucous membrane of the intestine it will be found, under the microscope, to consist of elongated cells with the free ends broad and the opposite ends narrow. The nucleus is situated towards the narrow end. Some of the cells in the epithelial lining of the intestine manufacture a transparent granular substance which collects in large vacuoles towards their free ends. It gives rise to slime or mucus which is secreted into the cavity of the intestine by the bursting of the cells. Due to the presence of vacuoles these cells are known as *goblet cells*.

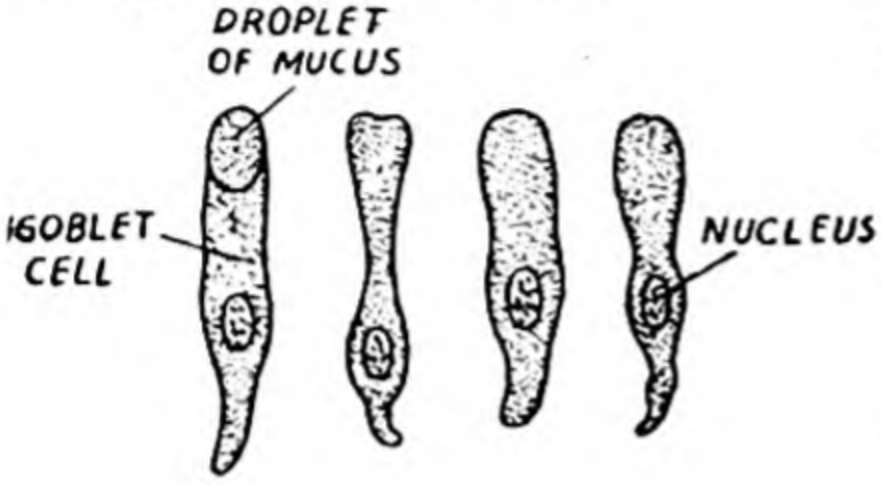

Fig. 65. Columnar epithelial cells from the intestine of the frog.

The *ciliated epithelium* (Fig. 66) consists of cells which bear at their free ends fine thread-like processes known as *cilia*. The cells are generally of the columnar type. In the frog the ciliated epithelial cells are found in the lining of the buccal cavity and may be obtained by scraping its roof. In the living condition the cilia constantly perform lashing movements by bending quickly and then straightening slowly. They do not, however, move in unison but in quick succession so that a wave is produced on the surface. Particles coming in contact with the surface, are, thus, driven in the direction of the wave. This may be demonstrated by removing the lower jaw of a freshly

killed frog, laying the animal on its back and placing a tiny piece of cork on the roof of the buccal cavity. The cork will be slowly carried towards the throat.

Muscular Tissue. The *muscular tissue* consists of elongated cells known as *muscle fibres* bound together by connective tissue. The muscle fibres possess the property of contraction to a high degree, by which the animal is able to perform various kinds of movements. There are two kinds of muscles, *striped* or *striated* and *unstriped*, *unstriated* or *smooth*. Striped muscles are generally voluntary, that is, they are under the control of the will, while the unstriped muscles are involuntary. Striped muscles are found in most parts of the body but the unstriped muscles are confined to some of

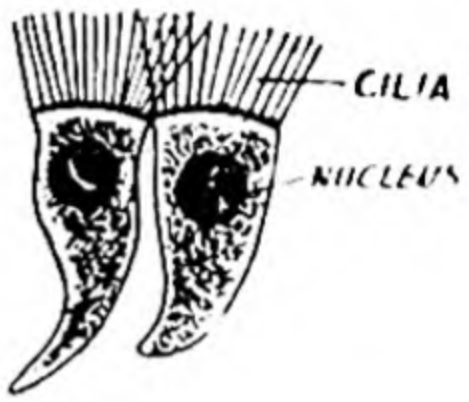

Fig. 66. Ciliated epithelial cells from the lining of the buccal cavity of the frog.

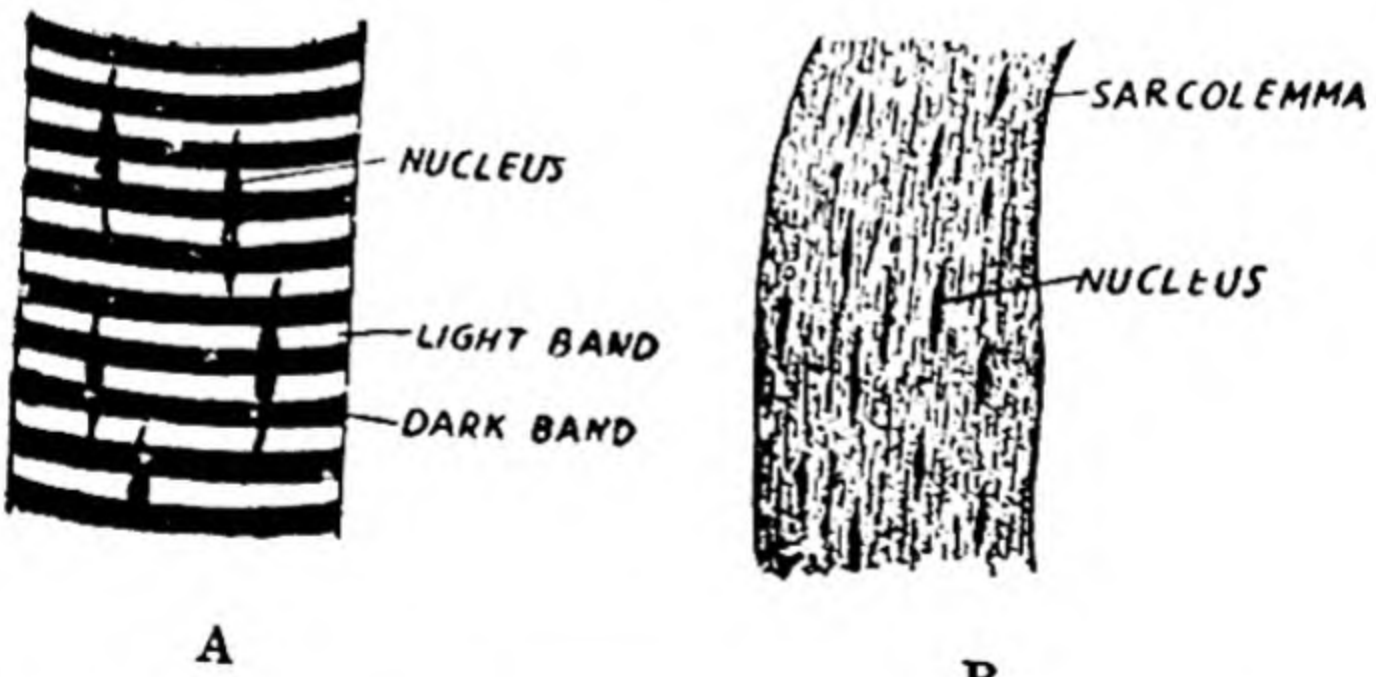

Fig. 67. A, portion of striped muscle fibre ; B, the same after treatment with distilled water followed by methyl-green.

the internal organs, such as the stomach, intestine and urinary bladder. The muscles of the heart are unique in being striped

but involuntary. Their structure, however, is different from the typical striped muscles.

Striped muscle (Fig. 67) is composed of long and cylindrical fibres. Under the miscroscope each fibre shows alternating light and dark transverse bands which give to the fibre a characteristic striated appearance. Each fibre has an outer covering membrane known as *sarcolemma* and a large number of spindle-shaped nuclei scattered in the substance of the fibre. Each fibre is, thus, a multinucleate cell. In the early stages of its development each muscle fibre contains a single nucleus but as the fibre grows the nucleus divides a number of times but the cytoplasm does not divide. The fibre, thus, becomes multinucleate.

Unstriped muscle fibres (Fig. 68) are shorter than the striped muscle fibres. Each fibre tapers at the two ends and contains a single oval nucleus near the centre.

Fig. 68. Unstriped muscle fibres from the intestine of the frog.

Skeletal Tissue. The *skeletal tissue*, unlike other tissues, is characterized by the presence of a large amount of intercellular or ground substance, known as *matrix*, which is secreted by the cells during the course of development. The main function of this tissue is to support and hold together various parts of the body. Due to the presence of abundant ground substance, connective tissue, cartilage, bone and blood are all considered as kinds of skeletal tissue.

The *connective tissue* is widely distributed in the body and binds different parts together. It connects the skin with muscles,

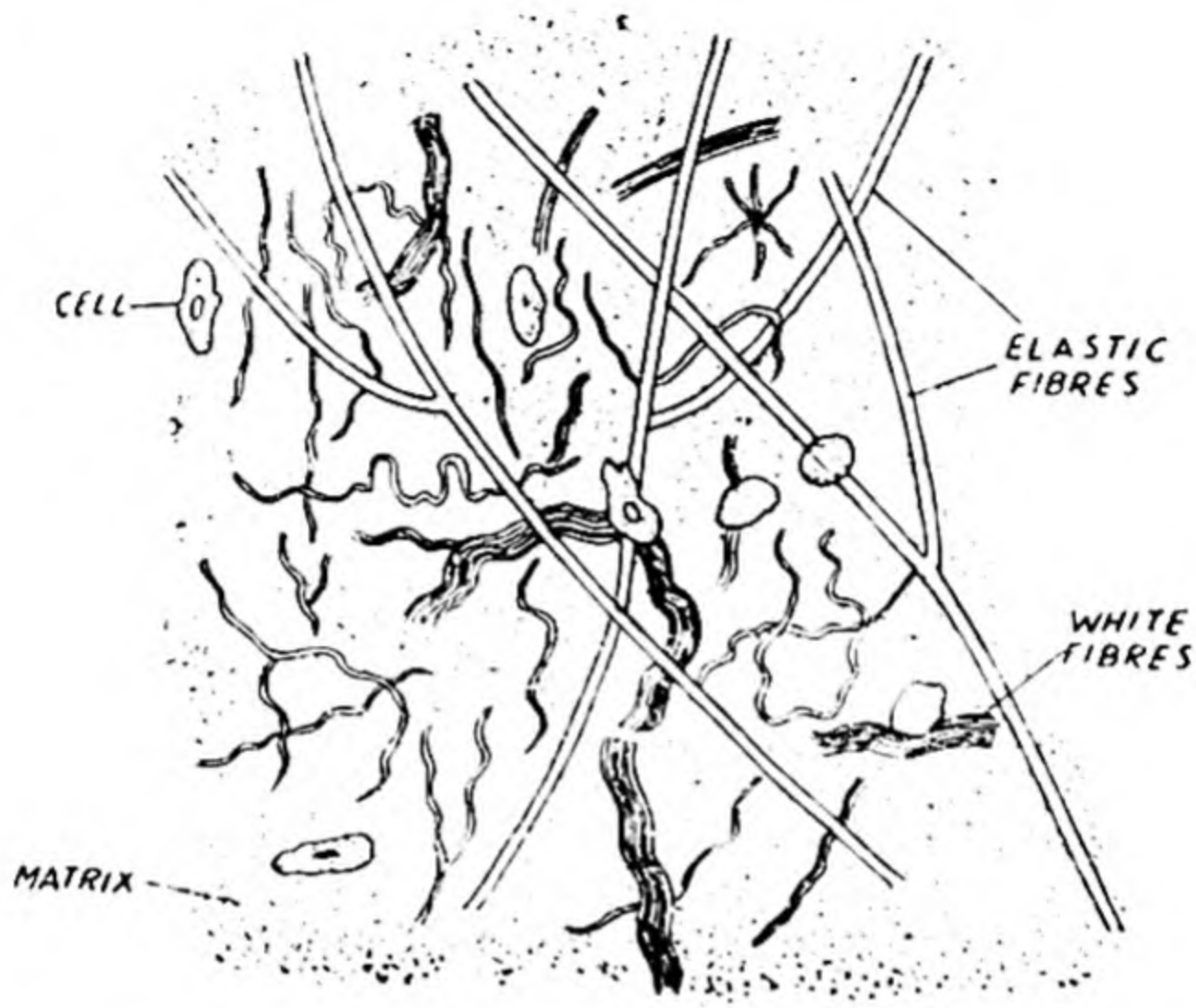

Fig. 69. Areolar tissue of the frog.

and the muscles with one another and with the bones. It has a number of varieties of which the *areolar tissue* (Fig. 69) is the commonest. A sample of this may be obtained from the membranes connecting the skin of a frog with the body-wall. When examined under the microscope it is found to consist of a clear homogeneous matrix in which are embedded connective tissue cells of various forms. Some of them are round while others are branching. The matrix contains two kinds of fibres, the *white fibres* and the *yellow* or *elastic fibres*. The white fibres usually occur in bundles, are wavy, unbranched and inelastic. The yellow fibres, on the other hand, occur singly, are straight,

branched and highly elastic. The matrix, when boiled, yields an organic substance known as *gelatin*.

Adipose tissue is a modified form of the ordinary areolar tissue. It contains a large number of connective tissue cells which become enlarged due to the formation of a globule of fat in each cell. The nucleus and cytoplasm, consequently, are pushed to the periphery. The adipose tissue occurs in the fat body and serves as a store of reserve food material

Cartilage is a firm and elastic tissue, which has three varieties, namely, *hyaline*, *fibrous* and *calcified*. *Hyaline cartilage* (Fig. 70), which is the commonest variety, is composed of a transparent and homogeneous matrix in which are scattered, irregularly, spaces or *lacunae* containing cartilage cells. The lacunae may be found singly or in groups of two or four, each lacuna containing one cell. In the embryo the cartilage is closely packed with cells which subsequently secrete the intervening matrix and move apart. At the same time each cell divides into two or more daughter cells, some of which remain close together to form groups. Hyaline cartilage is found at the ends of limb-bones and the sternum, between the vetebrae, in the pubis, hyoid and the larynx. In *fibrous cartilage* the matrix contains fibres which make it very tough. In *calcified cartilage*, which occurs in the suprascapula, the matrix is impregnated with lime salt The

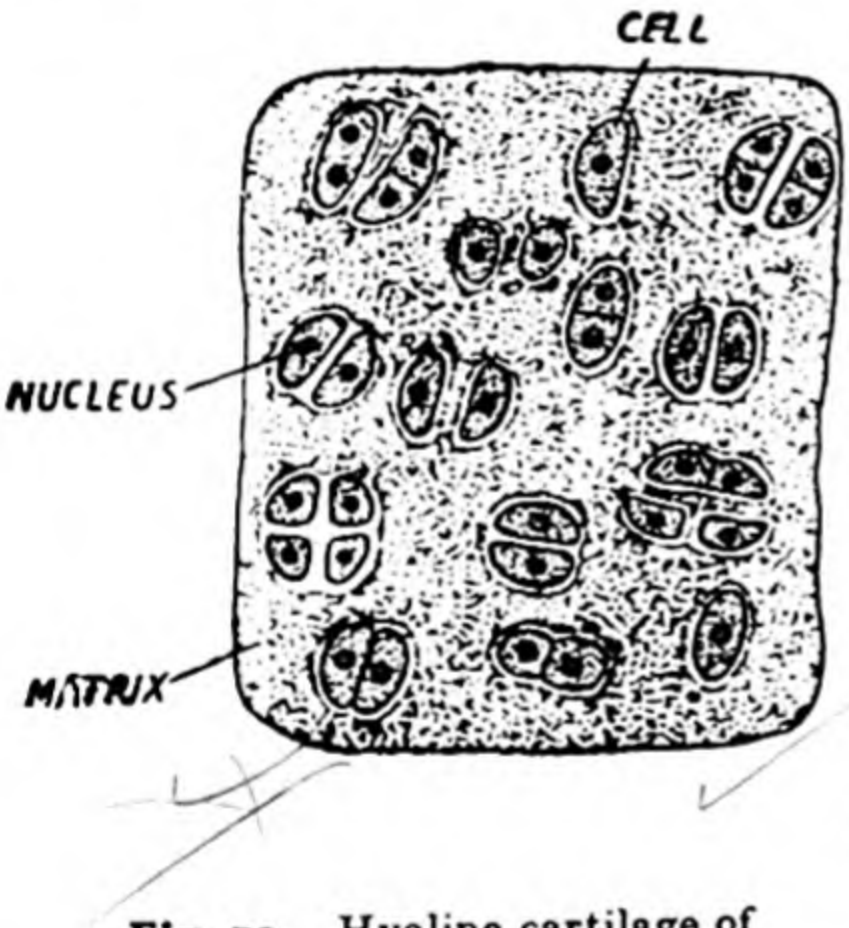

Fig. 70. Hyaline cartilage of the frog.

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matrix of cartilage on boiling gives out an organic substance known as *chondrin*.

Bone is composed of a hard matrix and bone-cells. The matrix consists of an organic base of gelatin which is impregnated with mineral salts chiefly calcium phosphate and calcium carbonate. Bone, thus, is made up of both mineral matter and animal matter. The mineral matter may be investigated by examining a dried bone under the microscope while the animal matter may be studied by examining a decalcified bone from which the mineral matter has been dissolved out by the action of an acid.

Microscopic examination of a thin section of a dried bone, such as the femur (Fig. 71), reveals that it is made up of a large number of concentric layers or *lamellae* arranged round the central *marrow cavity*. The lamellae contain numerous spaces, the *lacunae*, from which are given off in all directions fine branching tubes, the *canaliculi*, those of the neighbouring lacunae anastomosing with one another.

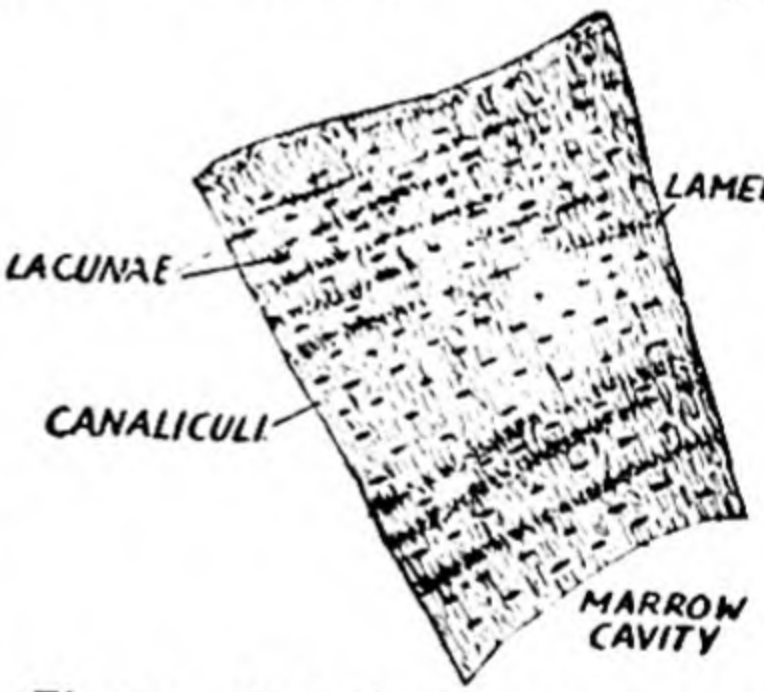
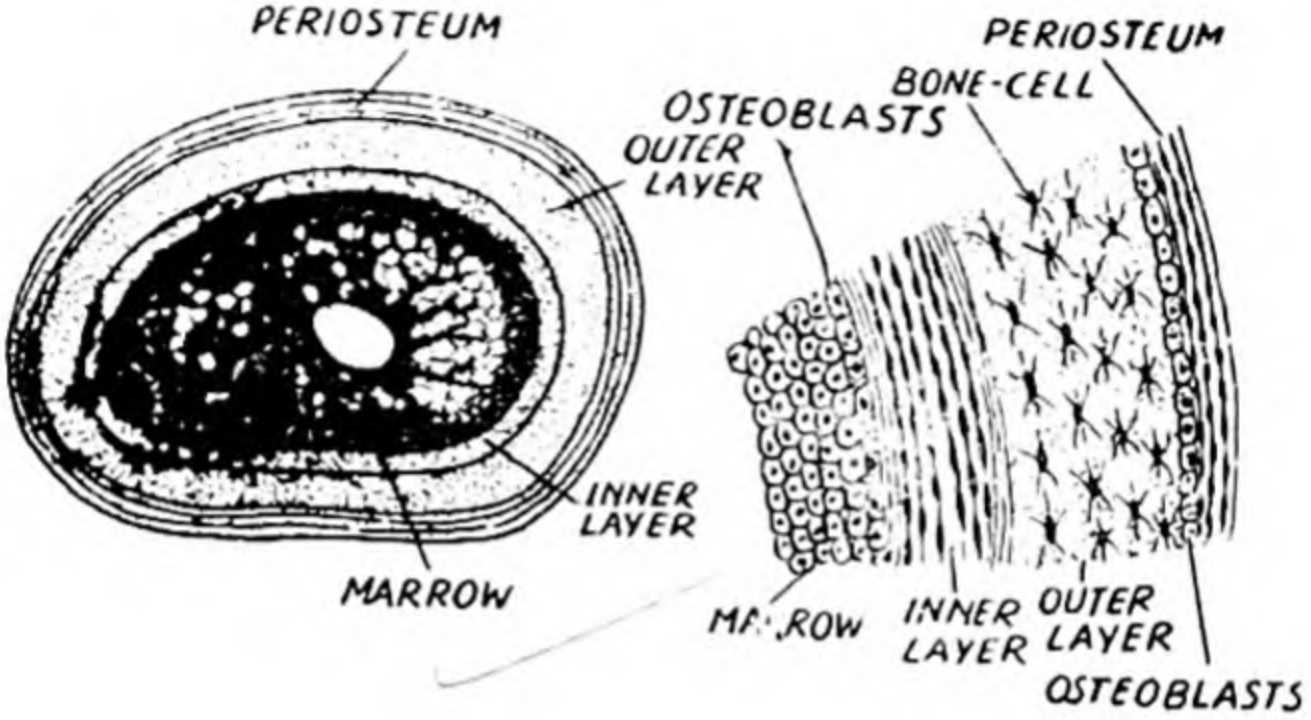


Fig. 71. Part of a transverse section of dry femur of the frog.

A section of decalcified bone (Fig 72) shows the marrow cavity to be filled with bone-marrow which is largely composed of adipose tissue and blood vessels. The marrow is surrounded by a fibrous substance arranged in two layers, an inner and an outer, and containing cell-spaces, corresponding to the lacunae of the dried bone. Each cell-space contains a bone-cell which

sends off delicate branching processes into the canaliculi. The neighbouring bone-cells are connected with one another through



A B

Fig. 72. A, transverse section of decalcified femur of the frog; B, part of the same (magnified). (After Howes).

these processes. The bone is covered by a tough fibrous sheath, the *periosteum*. A layer of bone-forming cells or *osteoblasts* lies just outside the marrow and another similar layer just inside the periosteum. By their activity new bone tissue is formed. The bone, thus, grows in size by the addition of successive layers on the outside as well as on the inside of the existing bone.

The *mammalian bone* (Fig. 73) differs from that of the frog in the arrangement of the lamellae. Just below the periosteum and around the marrow cavity the lamellae run parallel to the surface, as in the frog's bone, but elsewhere they are arranged in a concentric manner round numerous narrow canals, the *Haversian canals*, which contain minute blood vessels for

the nourishment of the bone. Each Haversian canal and its surrounding lamellae constitute a *Haversian system*. The spaces between the adjacent Haversian systems are filled by *interstitial lamellae*.

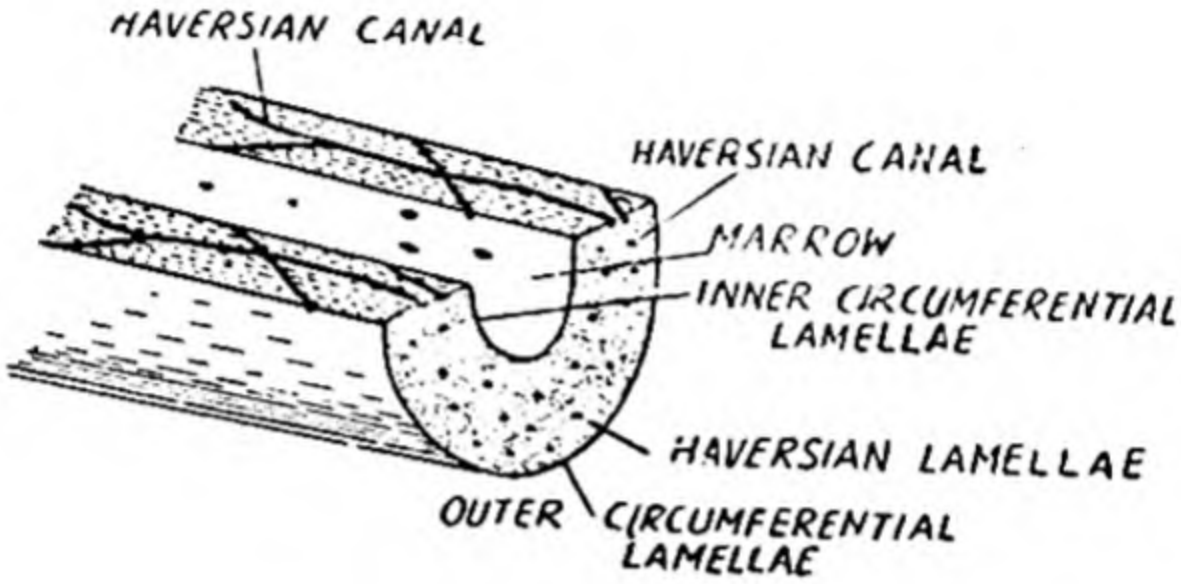


Fig. 73. A, transverse and longitudinal sections of a dried mammalian femur ; B, part of a transverse section of the same (magnified).

Blood (Fig. 46) consists of a fluid part, the *plasma*, and two

kinds of *corpuscles*, the *red* and the *white*, which float in the plasma. The plasma corresponds to the matrix of other skeletal tissues and the corpuscles to the cells. The matrix of the blood being fluid, can neither support nor bind together other tissues. The *red corpuscles* are oval in outline with a bulging central nucleus. They are in reality yellow in colour but appear red in a pile. The *white corpuscles* or *leucocytes* are nucleated, colourless and irregular in shape. If a film of fresh blood is examined under the microscope, the leucocytes will be seen to slowly change their shape by putting out short blunt processes or *pseudopodia* in various directions. The leucocytes can also perform creeping movements by putting out pseudopodia in one direction and withdrawing others from the opposite side.

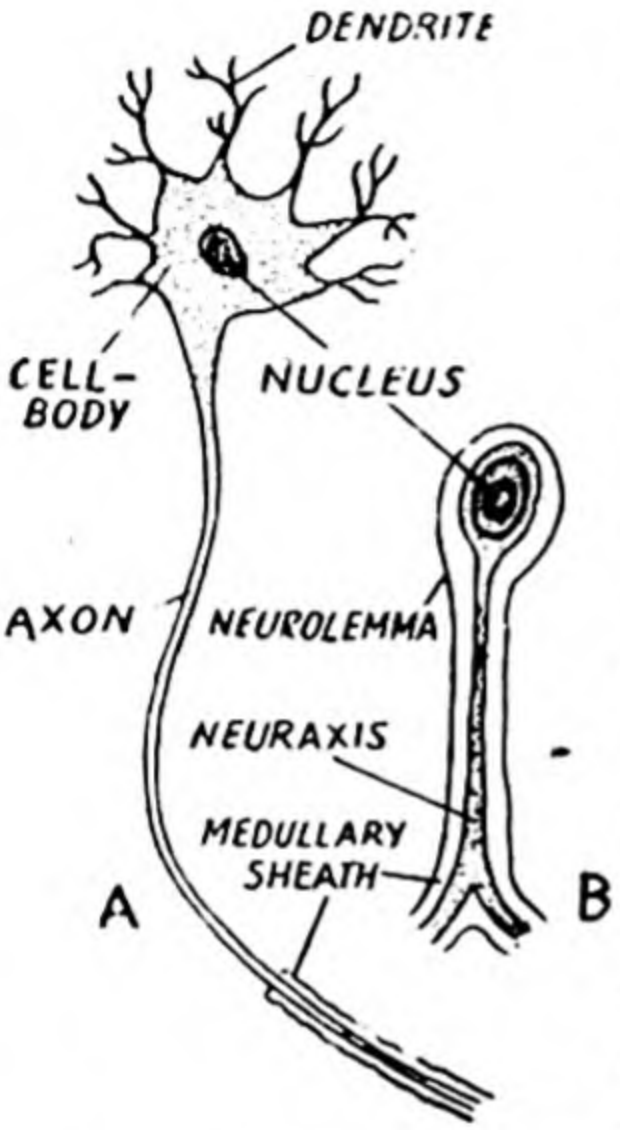


Fig. 74. A, a typical neuron : B, neuron from a spinal ganglion

Nervous Tissue. The nervous tissue is made up of nerve cells and nerve fibres. A typical nerve cell or *neuron* (Fig. 74) consists of (1) a large *cell-body* containing the nucleus, (2) a long process or *axon* arising from the cell-body, and (3) numerous short branched processes, the *dendrites* or *dendrons*. The axon normally conducts impulses away from the cell-body while the dendrites convey them toward the cell-body. The axon is continued into a nerve fibre to form its axis known as *neuraxis* This is surrounded by a sheath of a white fatty material, known as the

medullary sheath, which is covered by a delicate membrane, the *neurolemma* The medullary sheath is not continuous but is broken at intervals. The constrictions, thus formed, are known as the *nodes of Ranvier*. Just below the neurolemma are found at intervals nuclei which are surrounded by small amounts of granular cytoplasm. Nerve fibres, as described above, in which a medullary sheath is present, are known as *medullated* (Fig. 75) while those in which the medullary sheath is absent are called *non-medullated*. The latter are chiefly found in the sympathetic nervous system.

In the ganglia are present, in addition to nerve fibres, large neurons. In the spinal ganglia the cell-body of each neuron gives off, by a common stalk, two processes one of which is the axon and the other a dendron. The axon becomes the axis of a peripheral nerve fibre while the dendron enters the spinal cord. Here it sends off branches, each of which ends in a network, which is interwoven with a similar network arising from a neuron in the spinal cord or the brain.

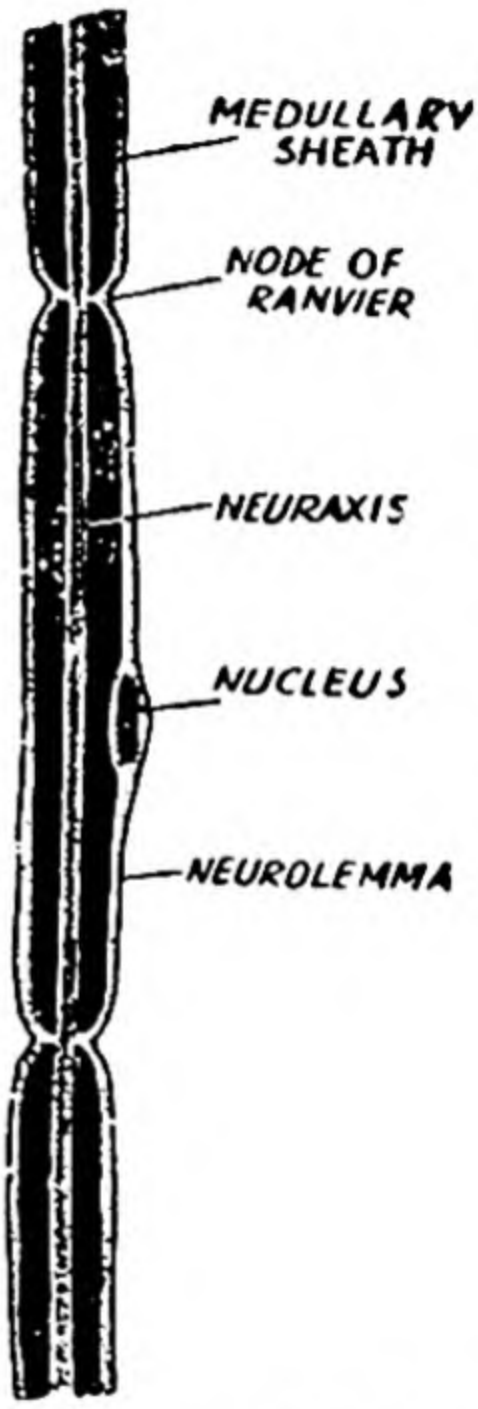


Fig. 75. A medullated nerve fibre.

CHAPTER XVI

HISTOLOGY OF THE FROG

COMPOUND TISSUES

The compound tissues are formed by the grouping together of two or more simple tissues. Their study involves an elaborate technique of section cutting which is beyond the scope of the present elementary book on Zoology. Prepared slides, may, therefore, be examined for the study of compound tissues, which include the skin, intestine, stomach, liver, pancreas, blood vessels, kidney, retina, testis and ovary.

Skin. A vertical section of the *skin* (Fig. 76), examined under the microscope, is found to consist of two distinct layers, an outer *epidermis* and an inner *dermis*. The *epidermis* is composed of several layers of cells. The outermost layer consists of squamous epithelium, its cells being broad and flat. Their protoplasm is converted into a horny substance and they, thus, constitute the *horny layer* of the epidermis which has a protective function. The horny layer, which consists of almost dead cells, is shed in small pieces and is constantly renewed by cells from the deeper layers. The innermost layer of the epidermis, known as the *Malpighian layer*, is made up of columnar cells which are fully alive and active. They multiply by binary fission. The new cells thus formed travel outward pushing the cells in front of them and becoming flattened and horny by the time they reach the outer surface of the skin.

The *dermis* consists of connective tissue with most of its fibres running horizontally, only a few vertical fibres being present at intervals. The dermis is richly supplied with blood capillaries which provide nourishment to the skin, and are

essential for cutaneous respiration. The dermis also contains nerve endings which make the skin sensitive to touch and changes in temperature. In the outer part of the dermis are found flask-shaped cavities lined by epithelial cells and known

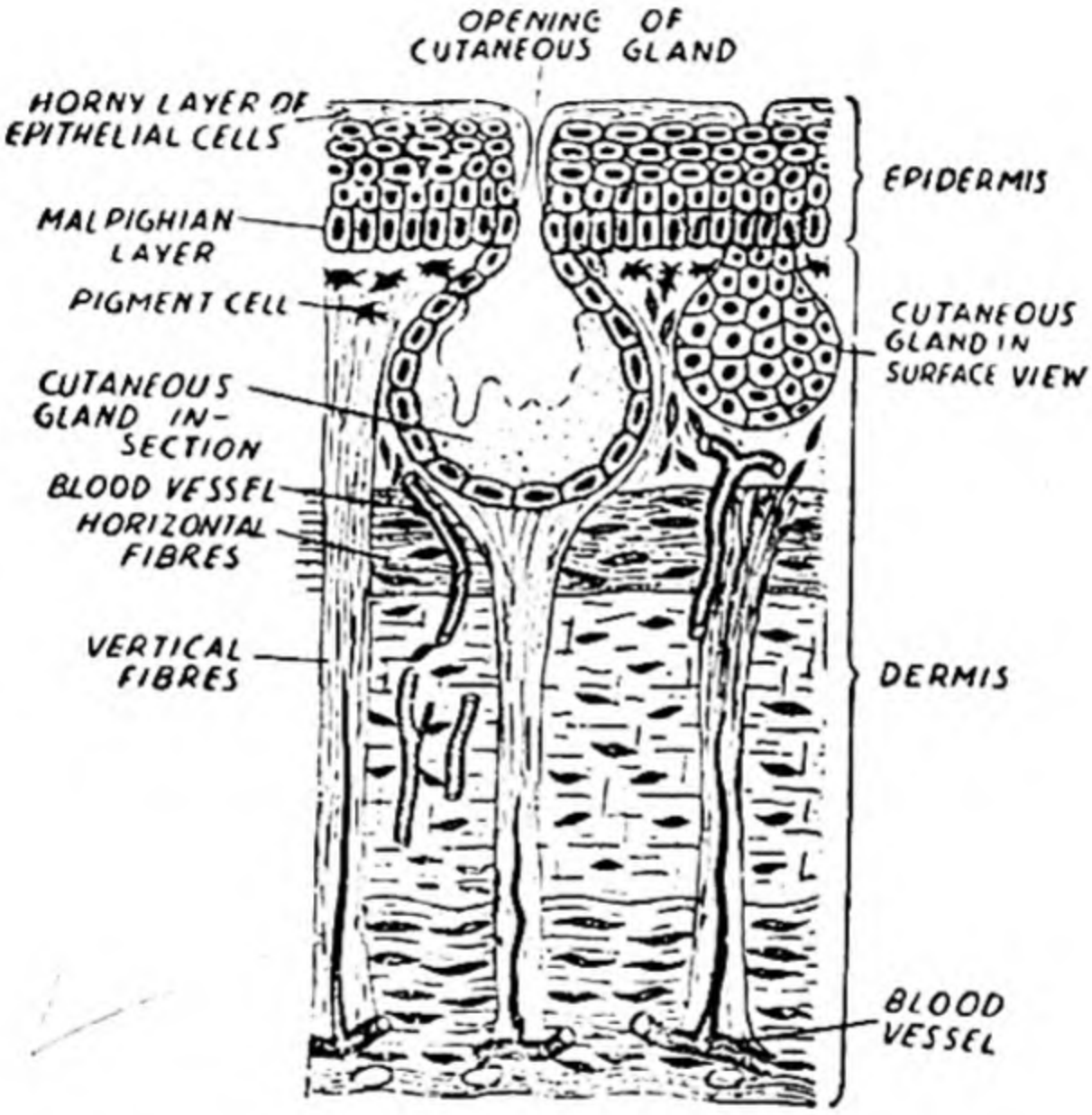


Fig. 76. Vertical section of the skin of the frog.

as *cutaneous glands*. The neck of each flask forms the duct of the gland which, after passing through the epidermis, opens at the surface of the skin. The cutaneous glands are formed by the sinking inwards of the epithelial cells of the epidermis and thus are epidermal in origin. The cells lining the glands secrete a slimy fluid which makes the skin slippery. Embedded in the

dermis are pigment cells which are irregular in shape. Their protoplasm contains pigment. They are particularly abundant in the superficial part of the dermis just below the epidermis. The characteristic colour of the frog's skin is due to the presence of pigment cells.

Intestine. Microscopic examination of a transverse section of the *intestine* (Fig. 77) shows that its wall is made up of four more or less distinct layers which are, from within outwards, (1) *mucosa*, (2) *submucosa*, (3) *muscular layer* and (4) *peritoneum*. The *mucosa* consists of a lining of columnar epithelial cells and a thin layer of connective tissue containing fine branches of blood vessels and nerves. Amongst the epithelial cells are found the mucus-secreting or *goblet cells*. The lining of the intestine therefore, is known as the *mucous membrane*. The *submucosa* consists of loose connective tissue traversed by larger blood vessels, lymphatics and nerves which send branches to the mucosa on the inner side and the muscular layer on the outer side. A thin sheet of muscle, the *muscularis mucosae*, is present in the submucosa. It is composed of two sets of unstriped muscle fibres, circular on the inner side and longitudinal on the outer side. The *muscular layer* surrounds the submucosa and is composed of unstriped muscle. It consists of an inner thick layer of circular muscle fibres and an outer thin layer of longitudinal muscle fibres. In a transverse section of the intestine the circular muscles are cut along their length and, thus, appear as spindle-shaped fibres whereas the longitudinal muscles are cut across and, therefore, appear as dots. The outermost layer of the intestine is the *peritoneum* which consists of an inner layer of connective tissue and an outer layer of squamous epithelium. It is continuous with the mesentery by which the intestine is suspended from the body-wall.

Stomach. The wall of the *stomach* (Fig. 78) consists of

the same four layersas that of the intestine but it differ froms the later not only in the greater thickness of the layers but also

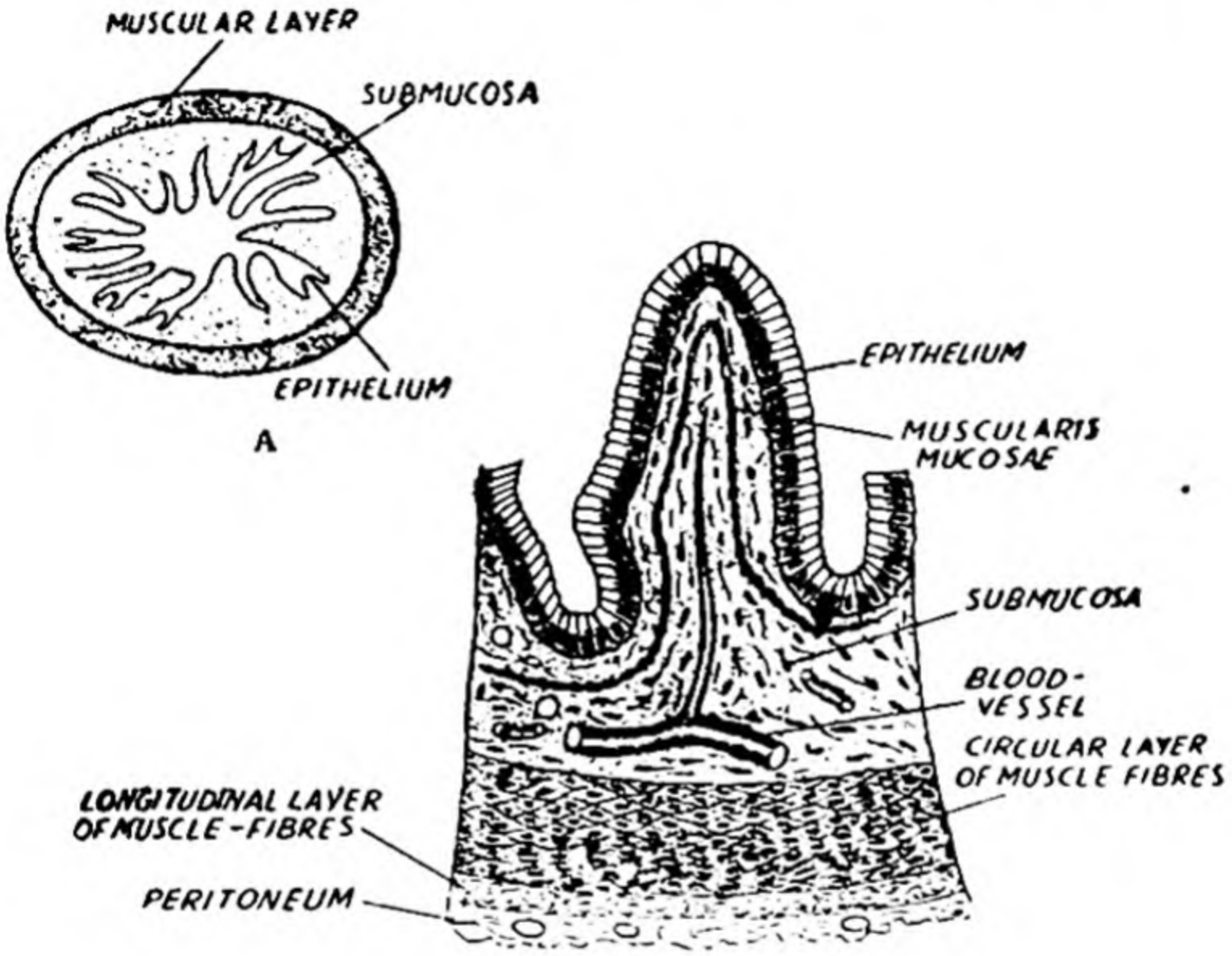


Fig. 77. A, transverse section of the ileum of the frog. B, part of the same highly magnified.

in certain other respects. The most important of these is the structure of the epithelium, instead of forming an even layer over the folds of the mucous membrane it is sunk into the underlying connective tissue to form simple or branched tubular glands known as the *gastric glands*. These are lined by a layer

of glandular cells which secrete the *gastric juice*. Each gastric gland opens into the cavity of the stomach by a small aperture

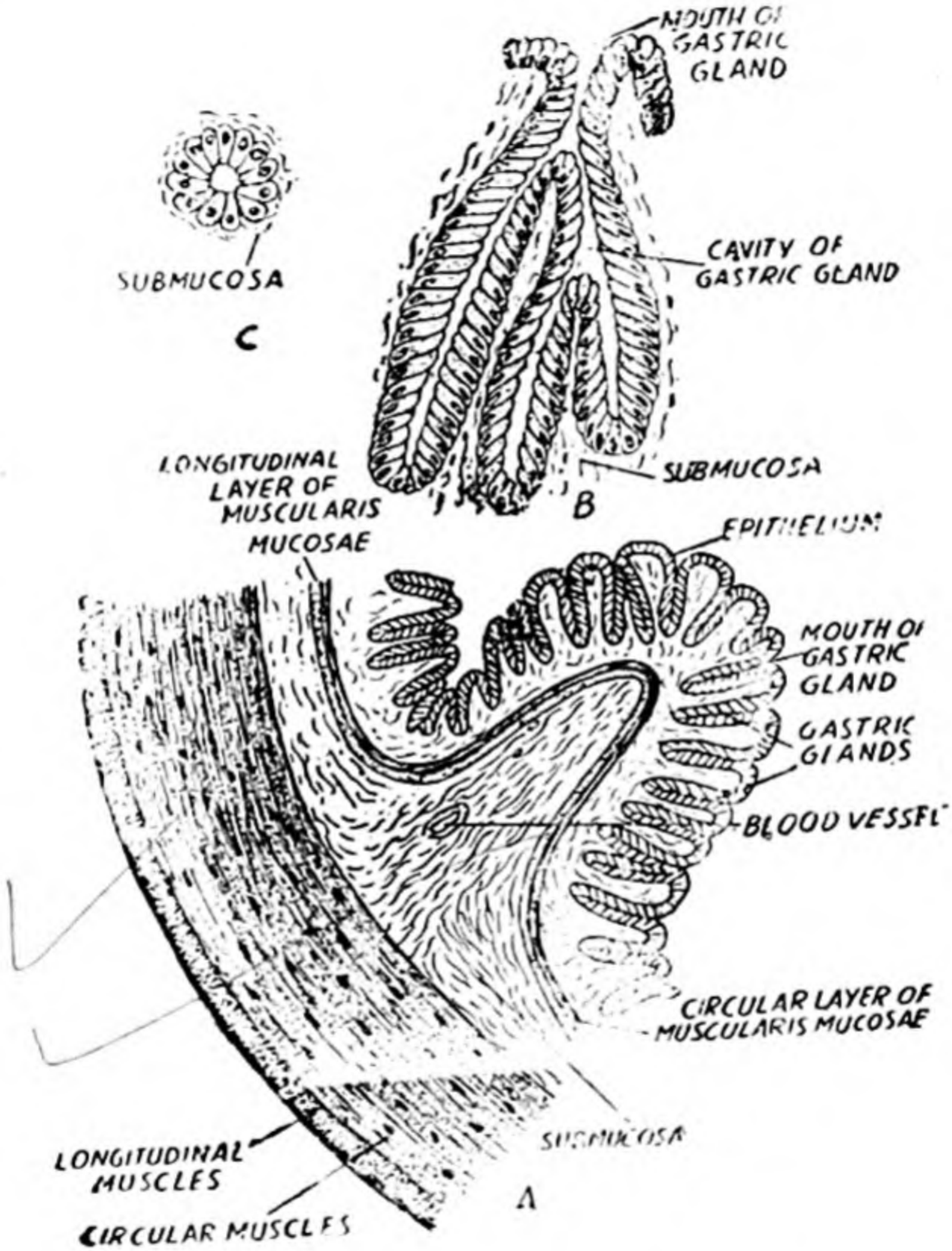


Fig. 78 A, part of a transverse section of the frog's stomach ; B, longitudinal section of a gastric gland ; C, transverse section of a gastric gland

through which the gastric juice is poured into that organ. The

layer of muscularis mucosae is better developed and is more regularly formed in the stomach than in the intestine.

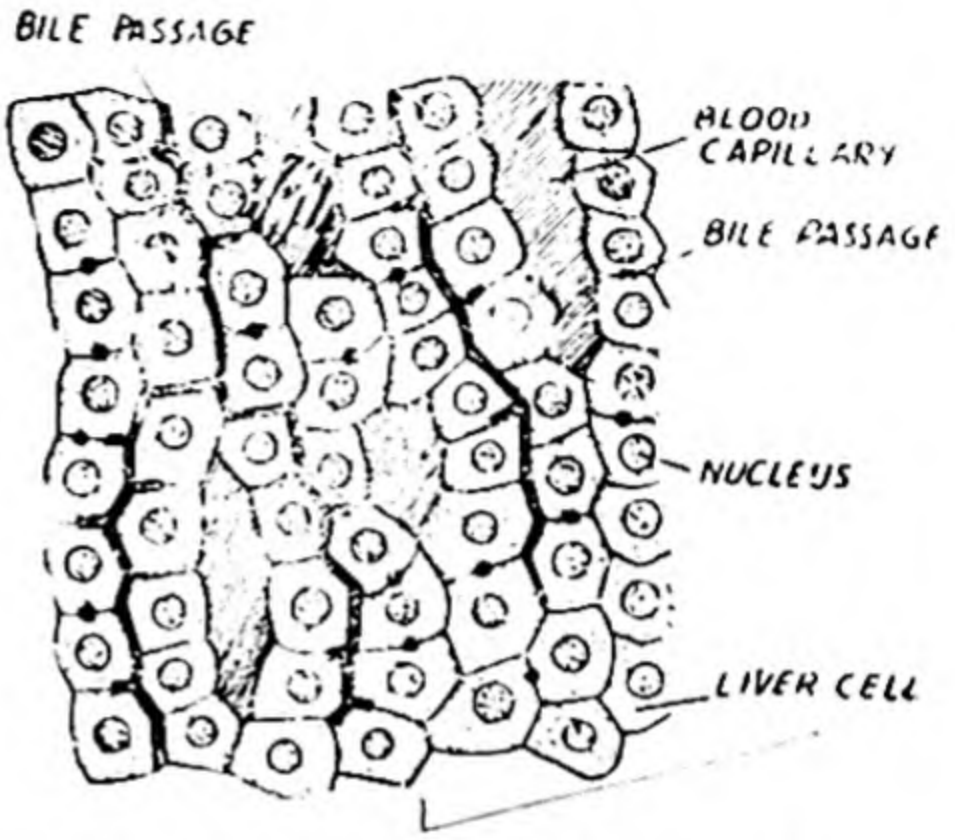


Fig. 79. Part of a section through the liver of the frog.

Liver. The *liver* (Fig. 79) is made up of columns of large potyhedral or many-sided cells, enclosing narrow channels, the *bile passages*. These passages unite with one another to form regular tubes lined by epithelial cells. The e unite repeatedly to form the *hep tic ducts* which finally open into the common bile duct. The liver cells secrete the bile which, passing through the various passages and ducts either goes directly into the intestine or collects in the gall-bladder. The liver is richly supplied with blood capillaries which arise partly from the hepatic artery and partly from the hepatic portal vein. The liver manufactures the bile out of the materials supplied to it by the blood.

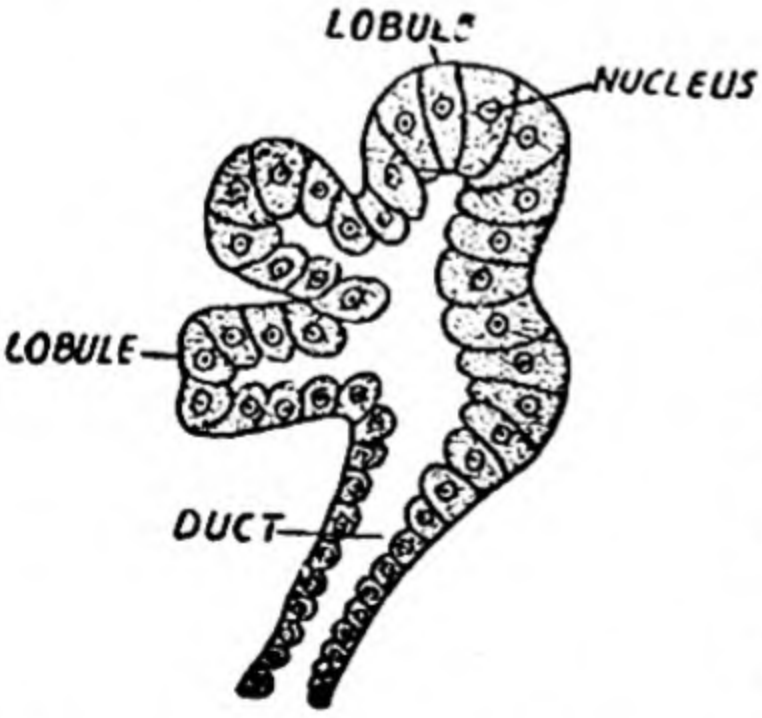


Fig. 80. Small portion of a section of the frog's pancreas.

Pancreas. The *pancreas* (Fig. 80) consists of a large

number of lobules arranged like grapes in a bunch, and held together by connective tissue. Each louble is lined by a layer of glandular cells and contains a narrow cavity in the centre. The cavities of adjacent lobules unite with one another and open into ducts lined by epithelial cells. These in turn unite to form the pancreatic duct which opens into the bile duct. Lying between the lobules and embedded in the connective tissue are groups of cells known as *islands of Langerhans* (Fig. 32). They produce the hormone known as *insulin*.

Blood Vessels. There are three types of blood vessels, namely, *arteries*, *veins* and *capillaries* Fig. (81). The wall of an *artery* is made up of three coats, an *inner* or *elastic* a *middle* or *muscular* and an *outer* or *areolar*. The inner coat consists of a layer of epithelial cells, the *endothelium*, which lines the lumen of the artery, and a layer of elastic tissue in the form of a membrane. The middle coat consists mainly of circularly arranged unstriped muscle fibres. The outer coat is formed of areolar connective tissue The strength of an artery depends largely upon the connective tissue layer as it does not get so easily torn as the other layers. A *vein* is composed of the same three coats as an artery but the elastic tissue is less developed and the muscular layer is much thinner. A vein, thus, has a thinner wall and wider lumen and is less elastic, as compared to an artery of the same thickness. The wall of a

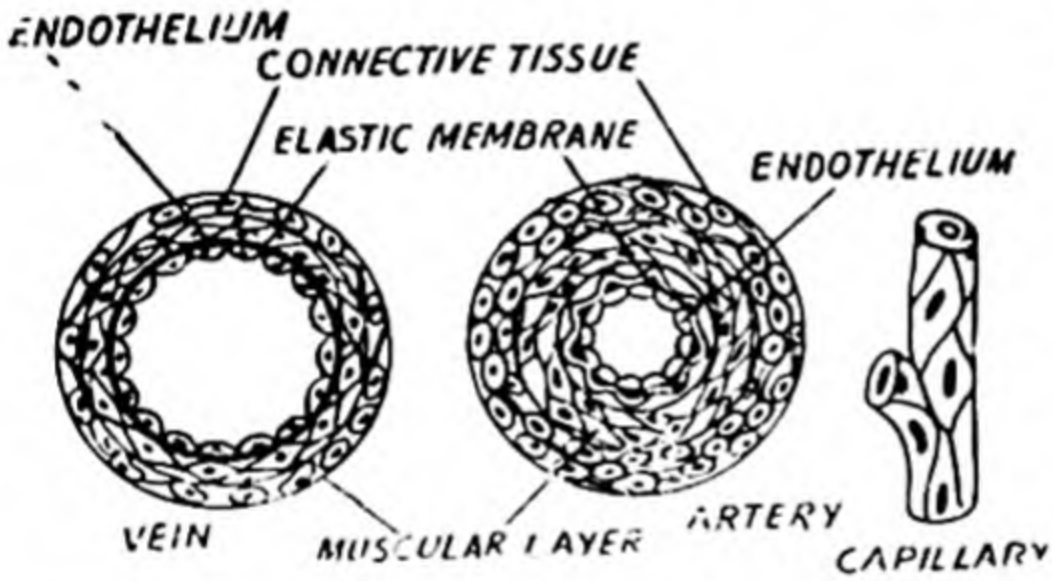


Fig. 81. Structure of blood vessels. Artery and vein, transverse sections ; capillary, surface view.

capillary is extremely thin, consisting of a single layer of flat epithelial cells corresponding to the endothelium of the other vessels.

Kidney. The *kidney* (Fig. 82) is made up of a mass of innumerable coiled tubules known as the *urinary tubules*. In a section of the kidney the tubules are cut in various planes and, therefore, present diverse outlines. The tubules are interwoven with a network of blood capillaries and are held together by connective tissue. Each urinary tubule (Fig. 83) is swollen at one end into a double-layered pouch, the *Malpighian capsule*, which contains a rounded bunch of blood capillaries, the *glomerulus*. The walls of the capsule are lined by flattened epithelial cells while those of the tubule by glandular cubical cells, which in some parts are ciliated. The urinary tubules open into *collecting tubes* which finally open into the ureter.

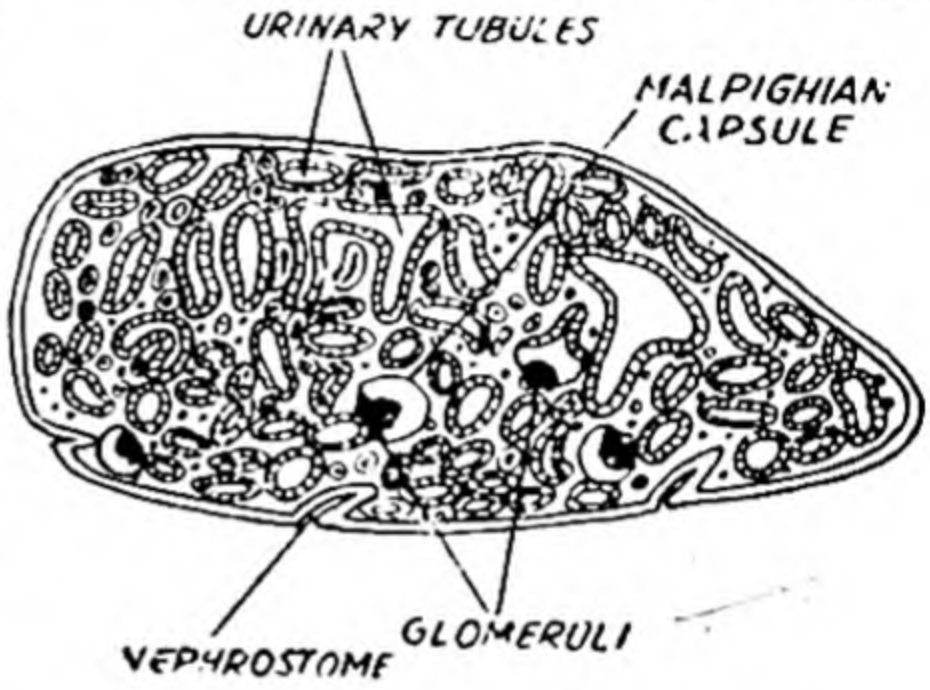


Fig. 82. Transverse section of the frog's kidney.

The blood is brought to the kidney by the renal arteries and the renal portal vein, and is carried away by the renal veins. The vessels entering the kidney break up into smaller vessels which ultimately form a network of capillaries in the substance of the kidney. The glomerulus is formed by a branch of a renal artery, which enters the capsule as the *afferent vessel* and breaks up into a bunch of coiled capillaries. These unite to form the *efferent vessel* which leaves the capsule by the same opening and joins the general capillary network.

It is now easy to understand the process of renalex creation. The cells of the Malpighian capsule take out water from

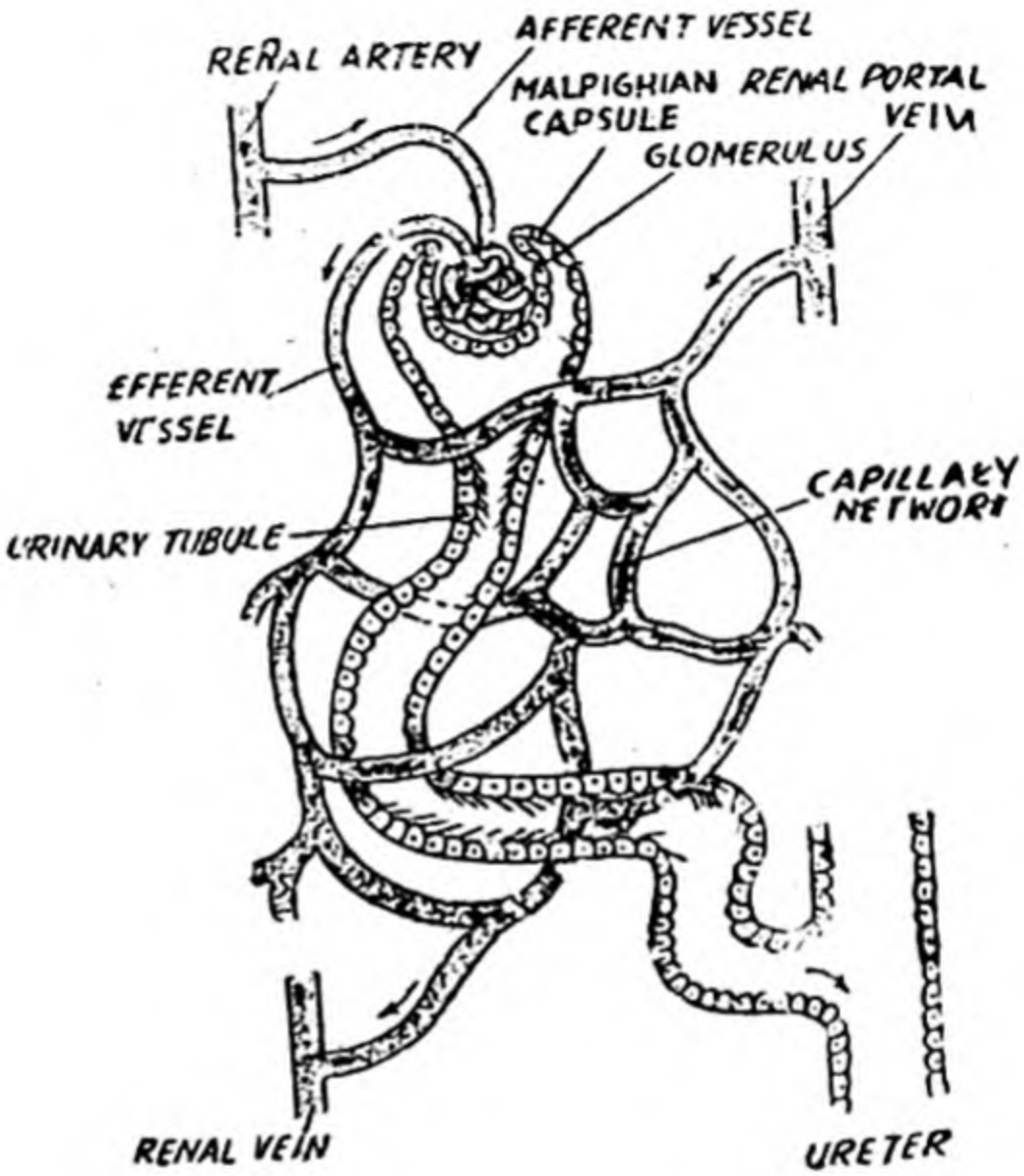


Fig. 83. A urinary tubule with its blood vessels (diagrammatic).

the blood while it is circulating through the glomerulus whereas the cells lining the rest of the tubule extract urea from the blood circulating in the general capillary network. Urea, which is a nitrogenous waste product, combines with water to form urine. By the action of the cilia in the wall of the tubule the urine is driven to the collecting tubes from where it passes into the ureter.

Retina. A verticle section of the *retina* (Fig. 84) examined under the microscope reveals that, in spite of its being thin and transparent, its structure is very complex, as it is made up of several distinct layers. Its innermost layer is composed of nerve fibres formed by the ramifications of the optic nerve after it has pierced the sclerotic, the choroid and the retina. Next to the layer of nerve fibres is a layer of nerve cells. This is followed by two granular layers and two nuclear layers alternating with one another. Finally the outermost layer is formed by highly sensitive epithelial cells known as *rods* and *cones*. The rods are more numerous than the cones. A layer of pigmented cells lies outside the rods and cones. It is generally considered to be a part of the choroid. Processes from the pigment layer extend into the layer of rods and cones.

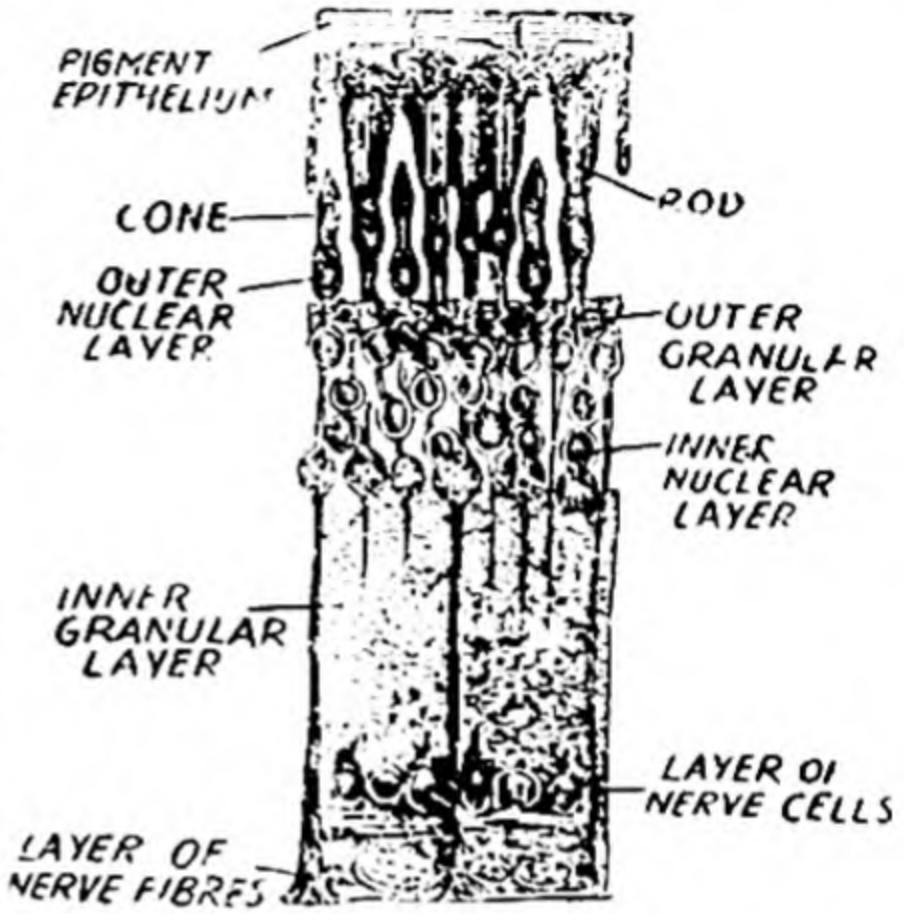


Fig. 84. Vertical section of the frog's retina. (After Marshall).

The rods and cones constitute the real organ of sight for it is they alone, of all the parts of the eye, which can receive images. The rays of light after passing through the several layers of the retina fall on the pigment layer which does not permit them to pass into the choroid. The rods and cones, which lie in contact with the pigment layer, are thus, stimulated. The image of the object received by them is transmitted to the brain through the fibres of the optic nerve. Although

the image is received by the rods and cones it is perceived only by the brain, without which there can be no sensation of sight.

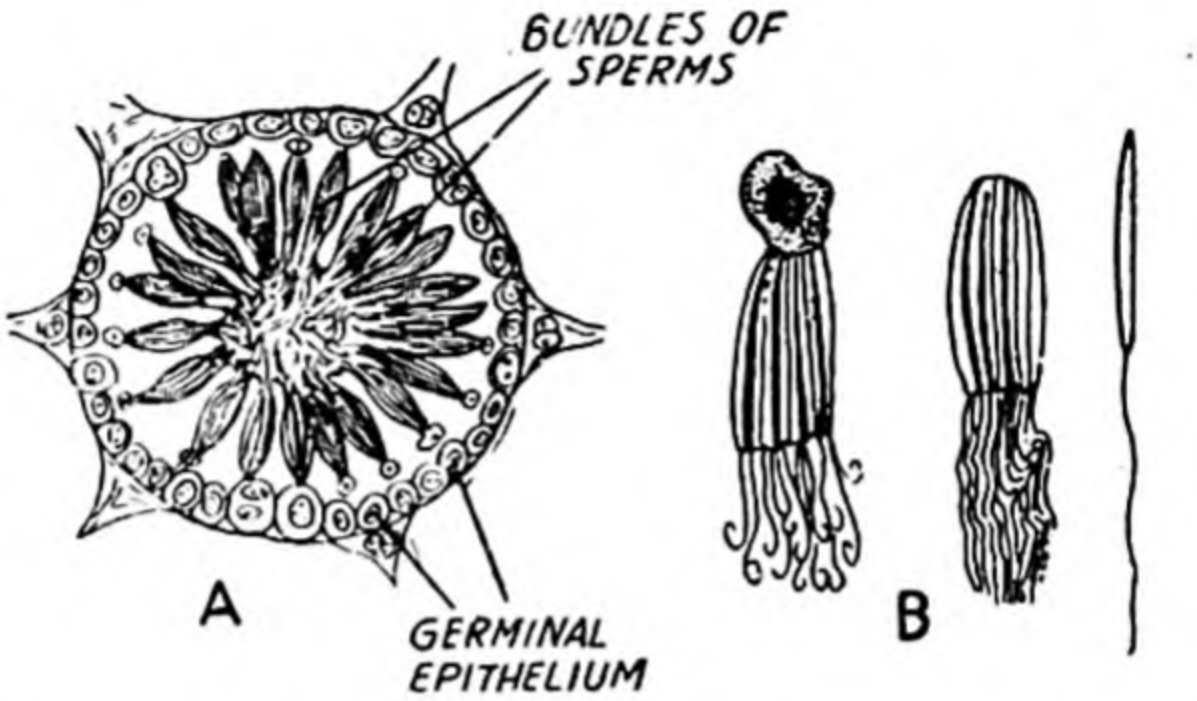


Fig. 85. A, transverse section of a crypt of the frog's testis
B, stages in the development of sperms.

Testis. The *testis* (Fig. 85) is covered by the peritoneum, and consists of a moss of tubules or *crypts* held together by connective tissue, which contains blood vessels and nerves. The crypts open into a central cavity which communicates with the corresponding kidney by means of the vasa efferentia. Each crypt is lined by a layer of *germinal epithelium* which gives rise to spermatogonia. By an elaborate process, known as *spermatogenesis* (p. 20), the spermatogonia are differentiated into the male germ cells known as *spermatozoa* or *sperms*. Each sperm consists of a rod-like head containing a nucleus and a long thread-like cytoplasmic tail. The sperm is able to swim actively in water by means of its vibratile tail.

Ovary. The *ovary* (Fig. 86) is a thin-walled folded sac the cavity of which is divided by partitions. The outer peritoneal covering of the ovary is modified to form the *germinal epithelium* from which the oogonia are budded

off. The ovary is lined internally by a layer of flattened epithelial cells. The middle portion of the wall of the ovary

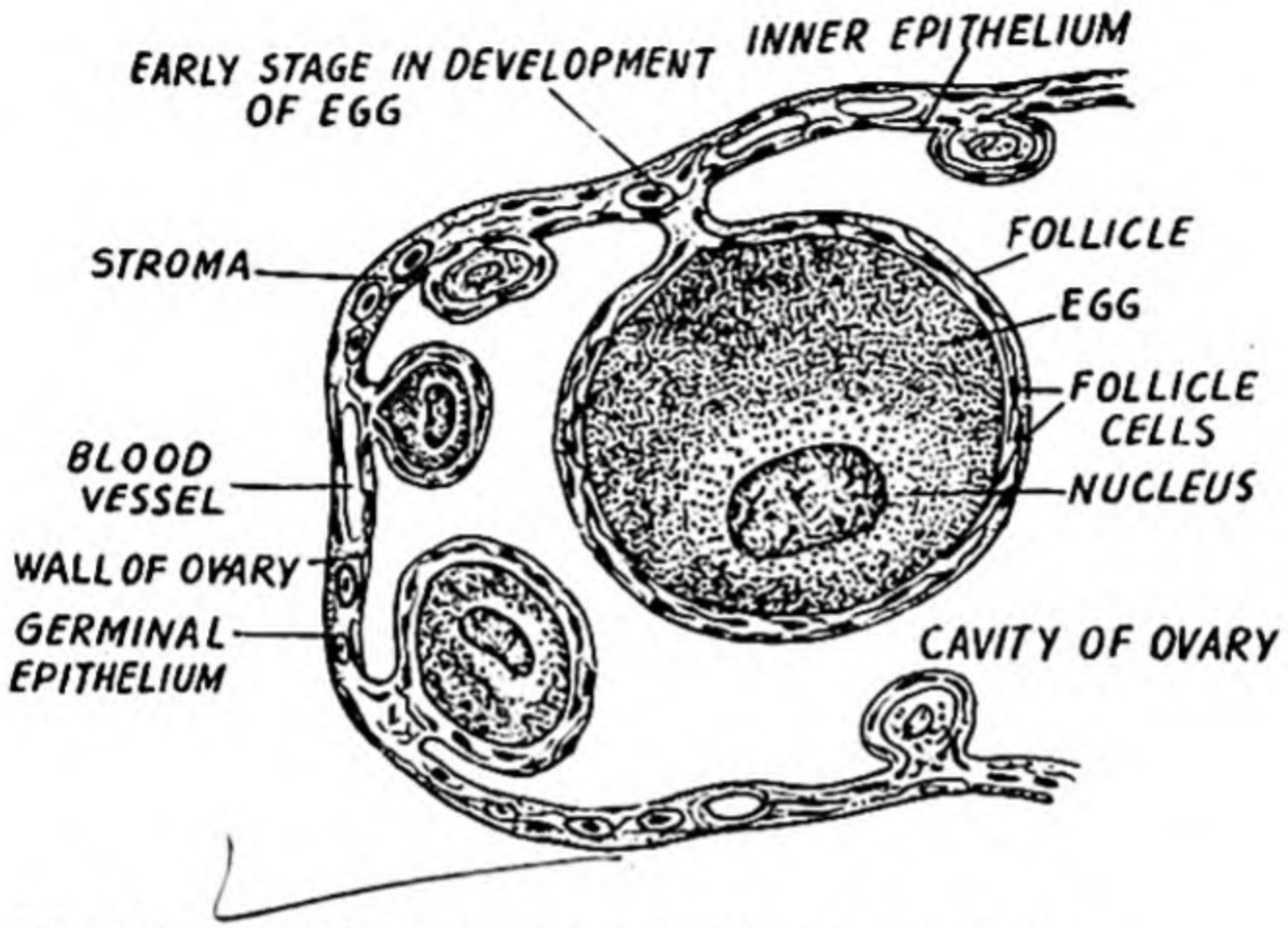


Fig. 86. Part of a section through the frog's ovary.

between the two layers is composed of connective tissue or *stroma*, containing blood-vessels and nerves. The oogonia are differentiated into mature ova by a complicated process known as *oogenesis* (p. 22). Groups of oogonia form *ovarian follicles* which are visible on the surface of the ovary as rounded projections. One of the many oogonia in each follicle develops into the mature ovum while the others form a peripheral layer of *follicle cells*. Within the follicle a non-cellular and transparent investing membrane, the *vitelline membrane*, is secreted by the ovum round itself. When the ovum is fully matured it is released into the body-cavity by the rupture of the follicle.

The *ovum* is a large rounded cell with a distinct nucleus which contains a number of nucleoli. The cytoplasm is laden with yolk, containing both albuminous and fatty granules, for

the nourishment of the growing embryo. The yolk granules become concentrated toward one pole, the *vegetative pole*, the opposite pole being known as the *animal pole*. As the ovum approaches maturity a superficial layer of black pigment becomes deposited over the animal pole, the vegetative pole remaining white.

CHAPTER XVII

DEVELOPMENT OF THE FROG

As described earlier (p. 28), the male frog during amplexus pours the spermatic fluid over the eggs laid in the water by the female. The eggs, then, are fertilized in the normal manner (p. 24) except that the spermatozoa have to pass through the jelly surrounding the eggs before entering the egg substance. It should be noted that fertilization in the frog takes place in the water outside the body of the female and is, thus, *external*. The fertilized ovum is easily visible to the naked eye. Its upper half is black and protoplasmic while the lower half is white and full of yolk. The upper pole, therefore is known as the *animal pole* and the lower pole as the *vegetative pole*. As the yolk is concentrated toward one pole the frog's ovum is known as *telolecithal*.

Segmentation. Soon after the ovum is fertilized it begins to divide or *segment*. A vertical furrow, passing through the poles, appears around it which, deepening gradually, divides the ovum into two equal cells or *blastomeres*. The division of the cytoplasm is preceded by the division of the nucleus so that each blastomere, which is black above and white below, contains a nucleus. A second vertical furrow, at right angles to the first, divides each blastomere into two so that there are four similar blastomeres each having a black and a white pole and containing a nucleus. The third furrow is horizontal, passing a little above the equator and at right angles to the other two. Eight blastomeres are thus formed of which the upper four are black and small, and the lower four white and large. The former are known as *micromeres* and the latter as *megameres*. This division is, therefore, *differential*. As each

cleavage completely divides the cells into two, the segmentation is known as *holoblastic*, but, as it does not produce cells of equal size, it is *unequal*.

Further divisions of the eight blastomeres take place, but the micromeres, being free from yolk, divide more rapidly than the yolk-laden megameres. This results in the formation of a solid mass of cells, the *morula* which consists of micromeres above and megameres below. Soon a cavity appears in the upper half of the morula converting it into a hollow ball of cells known as the *blastula*. Its wall is made up of micromeres in the upper part and megameres in the lower part. Its cavity, which is filled with a fluid, is known as the *segmentation cavity* or the *blastocoele*.

The micromeres, owing to their more rapid multiplication, encroach upon the megameres. This process of overgrowth of the micromeres is known as *epiboly*. The micromeres however, do not completely cover the megameres but leave a small aperture through which the latter are visible. The aperture is known as the *blastopore* and the plug of yolk-laden cells, with which it is filled, is known as the *yolk-plug*. The blastopore marks the posterior end of the embryo.

The blastopore first appears as a crescentic groove. As the micromeres spread downwards, some of them roll inwards over the margin of the groove, which subsequently becomes the dorsal lip of the blastopore. This process of inturning of the micromeres is known as *involution*. The two processes of epiboly and involution, thus, take place simultaneously. The dorsal lip of the blastopore gradually extends downwards on either side forming the lateral lips and these eventually meet below to form the ventral lip.

The involution of dorsal lip cells marks the beginning of a second cavity in the embryo, starting at the blastopore and gradually extending inwards. It communicates, at first, with the

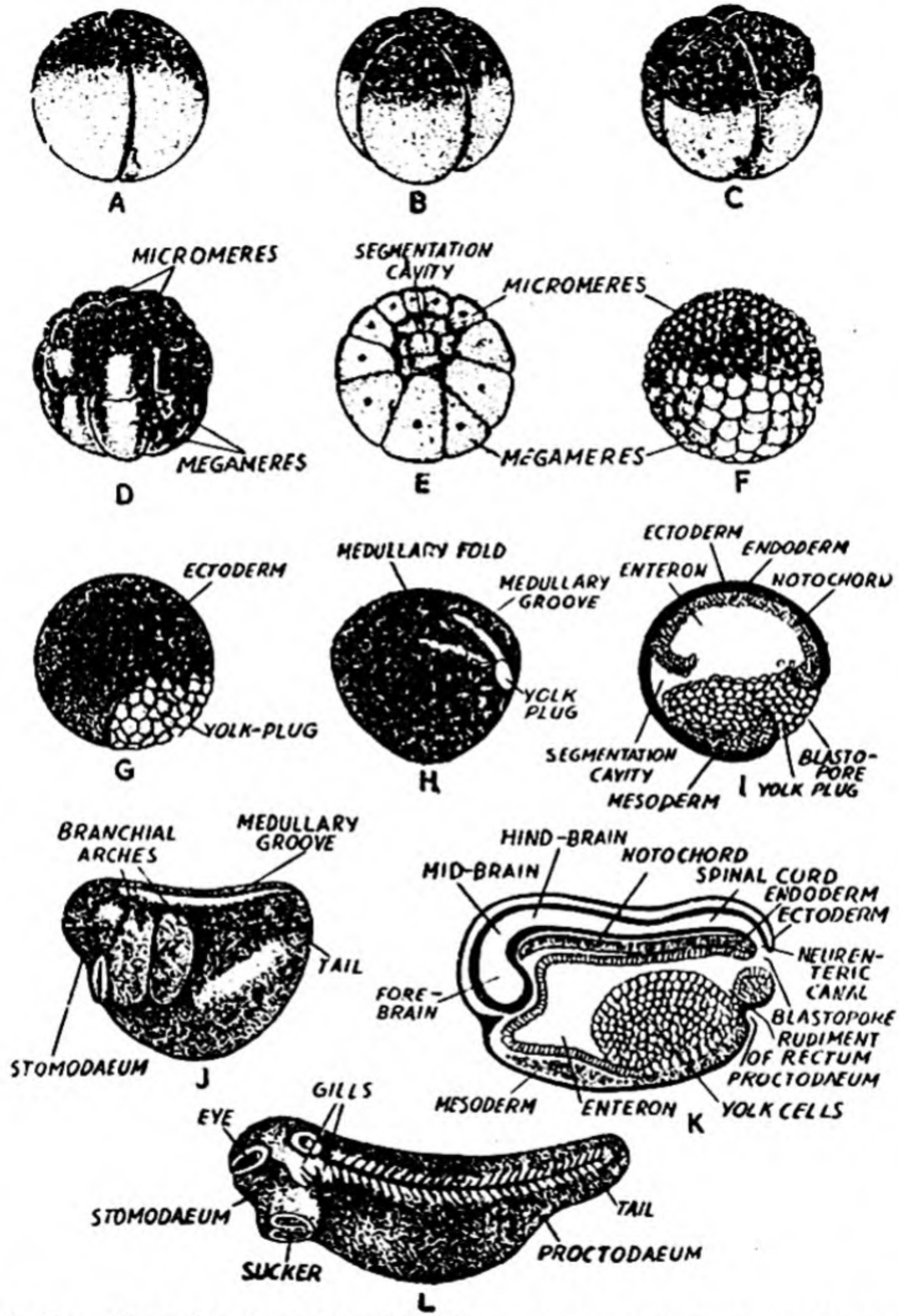


Fig. 87. Early development of the frog. A, two-celled stage ; B four-celled stage, ; C, eight-celled stag ; D, morula ; E, section of blastula ; F-G, overgrowth of ectoderm ; H, gastrula ; I, section of embryo showing germinal layers ; J, assumption of tadpole form ; K, establishment of nervous system, notochord and alimentary canal (longitudinal vertical section) ; L, newly hatched tadpole.

exterior through the blastopore but soon becomes closed. This new cavity, which is destined to become the alimentary canal of the adult, is known as the *enteron* or *archenteron*. The floor and side-walls of the enteron are derived from the megameres while the roof is formed by the involuted micromeres. With the growth of the enteron the segmentation cavity gradually becomes smaller and finally disappears. The blastula has now been converted into *gastrula*.

The embryo at this stage is two-layered or *diploblastic*, each layer being several cells thick. The outer layer of cells covering the embryo and derived from the micromeres, is known as the *ectoderm* or *epiblast*. The cells lining the enteron and derived partly from the involuted micromeres but largely from the megameres constitute the *endoderm* or *hypoblast*. A large number of unaltered megameres or yolk-cells are still present at the bottom of the enteron to provide nourishment to the growing embryo.

A third layer of cells, known as the *mesoderm* or *mesoblast*, is formed between the ectoderm and the endoderm. It has been stated that the micromeres which grow in at the upper lip of the blastopore form the roof of the enteron and, thus, constitute a part of the endoderm. The micromeres at the lateral and ventral lips of the blastopore, by involution, give rise to the mesoderm. These cells extend inwards as a pair of mesodermal sheets between the ectoderm and the endoderm on the two sides of the enteron. By further growth the two sheets become continuous except along the mid-dorsal line. The three *primary* or *germinal layers* of the body, namely, the ectoderm, mesoderm and endoderm, are thus established. The embryo now becomes three-layered or *triploblastic*.

Development of Organs. All the organs of the body arise from the three germinal layers by a process of differentiation. A detailed account of this very complicated process is

beyond the scope of the present book. So a mere outline of the development of the more important structures will be given here.

The *nervous system* makes its appearance at a very early stage of development. The deeper layers of the ectoderm on

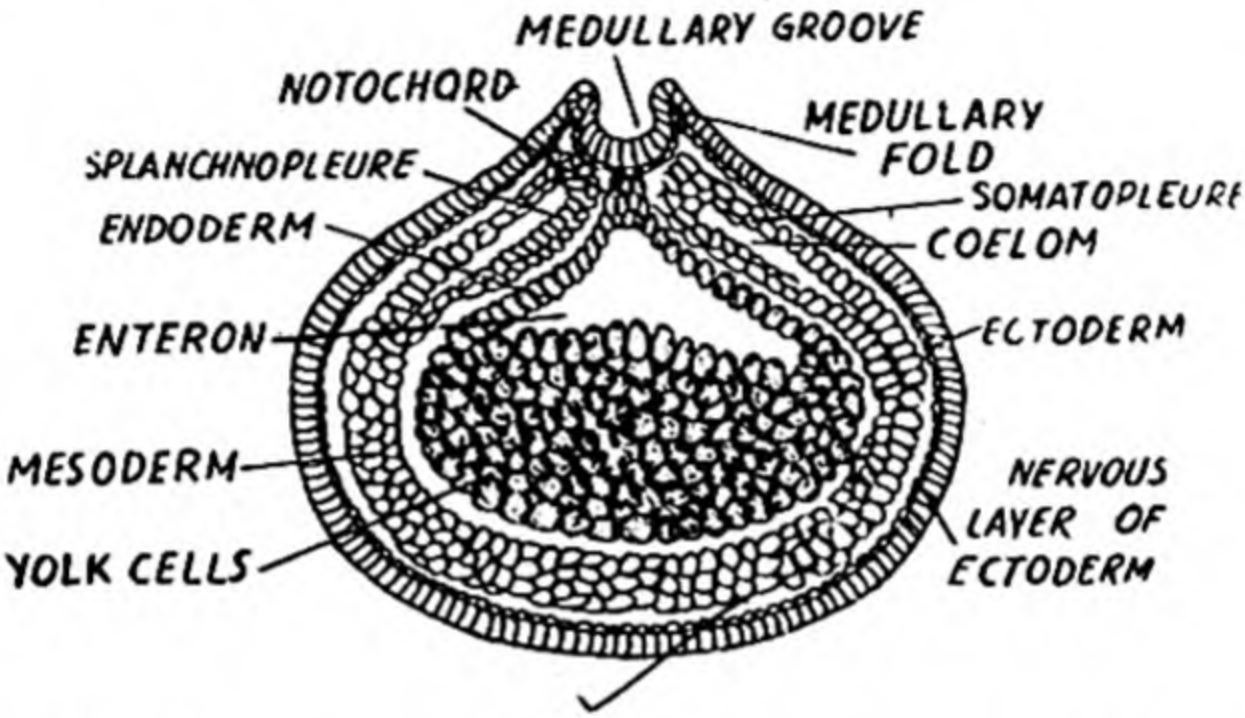


Fig. 88. Transverse section through a frog's embryo before the closure of the medullary folds.

the dorsal surface become thickened to form a plate, the *medullary plate*. The walls on the sides of the plate grow upwards to form two ridges, the *medullary folds*, enclosing a groove, the *medullary groove*. The edges of the medullary folds now fuse with each other above the groove which is thus converted into a tube, the *medullary tube*. This, for a time, communicates with the enteron by a passage, the *neurenteric canal*. The medullary tube is modified, by the thickenings of its walls, into the brain in front and the spinal cord behind. The brain, in its early stages of development, consists of three vesicles arranged in a row one behind the other. These are known as the *fore-brain*, *mid-brain* and *hind-brain*. During the course of development the fore-brain gives rise to the olfactory

lobes, cerebral hemispheres and diencephalon, the mid-brain to the optic lobes and the crura cerebri, and the hind-brain to the cerebellum and the medulla oblongata.

Early in development the *notochord*, around which the vertebral column is subsequently developed, appears as a rod-like structure by the thickening of the endodermal cells in the mid-dorsal line of the enteron just below the medullary tube. These cells were originally derived from the micromeres which involuted at the upper lip of the blastopore, and formed the dorsal wall of the enteron. While the notochord is being formed, the two side-walls of the enteron grow upwards and meet each other in the mid-dorsal line below the developing notochord. The walls of the enteron, thus are eventually formed by the endodermal cells which originated from the megameres. For a time the notochord is the only skeleton of the embryo. It extends from the blastopore to the pituitary body.

The mesoderm at first forms a continuous mass of cells filling up the whole space between the ectoderm and the endoderm but very soon splits up into two layers, the outer lying just inside the ectoderm and the inner just outside the endoderm. The former is known as the *parietal* or *somatic layer* of the mesoderm and the latter as the *visceral* or *splanchnic layer* of the mesoderm. The space between the two is the *coelom*. The somatic layer and the ectoderm together form the body-wall or *somatopleure* while the splanchnic layer and the endoderm both form the wall of the enteron or *splanchnopleure*.

The embryo now becomes elongated. Its anterior end becomes rounded and a sucker is developed on it. At the posterior end a tail is formed. Above the sucker a depression, the mouth-pit or *stomodaeum*, appears and another similar depression, the *proctodaeum*. appears below the tail. The stomodaeum and the proctodaeum at a later stage, give rise

to the mouth and the cloaca respectively and establish communication with the enteric cavity. Two pairs of branched processes, the *external gills*, attached to the first and second branchial arches, arise from the sides of the head. They are richly supplied with blood capillaries and serve as organs of respiration. The oxygen, dissolved in the water, is taken in and carbon dioxide is given out.

Fate of Germinal Layers. As stated above all the organs of the adult frog are derived from the three germinal layers of the embryo. The structures which arise from each of the three layers are as follows :—

Ectoderm :
Epidermis and cutaneous glands.
Nervous system.
Eyes, ears and nasal cavities.
Lining of the stomodaeum and the proctodaeum.

Mesoderm :
Dermis.
Skeletal system (connective tissue, cartilage and bone).
Walls of the alimentary canal except the lining.
Muscular system.
Circulatory system.
Excretory system.
Reproductive system.
Lining of the coelom.

Endoderm :
Lining of the alimentary canal except the stomodaeum and the proctodaeum.
Lining of the lungs.
Parts of the liver and pancreas.
Lining of the urinary bladder.
Notochord.

Larval History. The newly hatched larva of the frog is a small fish-like creature, known as the *tadpole*. It lives in

water and swims about freely or attaches itself to a water-weed by means of the sucker. It cannot feed for some time as there is no mouth and the stomodaeum does not open into the archenteron. It breathes in water by means of the two pairs of external gills.

Soon, however, the stomodaeum establishes a communication with the enteron. The mouth is formed and is provided with a pair of horny jaws and the lips with horny papillae. By means of these it nibbles at the weeds, being altogether herbivorous at this stage of its existence. The enteric canal rapidly elongates and the intestine, which is visible through the transparent abdominal wall, becomes coiled like a watch-spring. The comparatively long alimentary canal of the tadpole is due to its vegetable diet which, being less nourishing, bulk for bulk, than animal diet, has to be taken in a larger quantity. A third pair of external gills is formed on the third branchial arch, behind the first two pairs which increase greatly in size. The eyes make their appearance but the sucker is lost. On either side of the head, in the pharyngeal region, a series of four *gill-clefts* or *gill-slits* makes its appearance. The first gill-cleft lies between the hyoid arch and the first branchial arch while the remaining three gill-clefts lie between the successive branchial arches. A fold of the skin, the *operculum*, arises from either side of the head, in front of the external gills and extends backward so as to cover the gills and the gill-clefts The two opercula meet each other ventrally and their posterior margins become fused with the body-wall. A *branchial chamber* is thus formed which opens to the exterior by a single aperture, the *spiracle*, situated in the posterior wall of the chamber on the left side.

Soon after the appearance of the opercular folds the external gills shrivel up and are replaced by four pairs of *internal gills* formed in relation with the branchial clefts. The

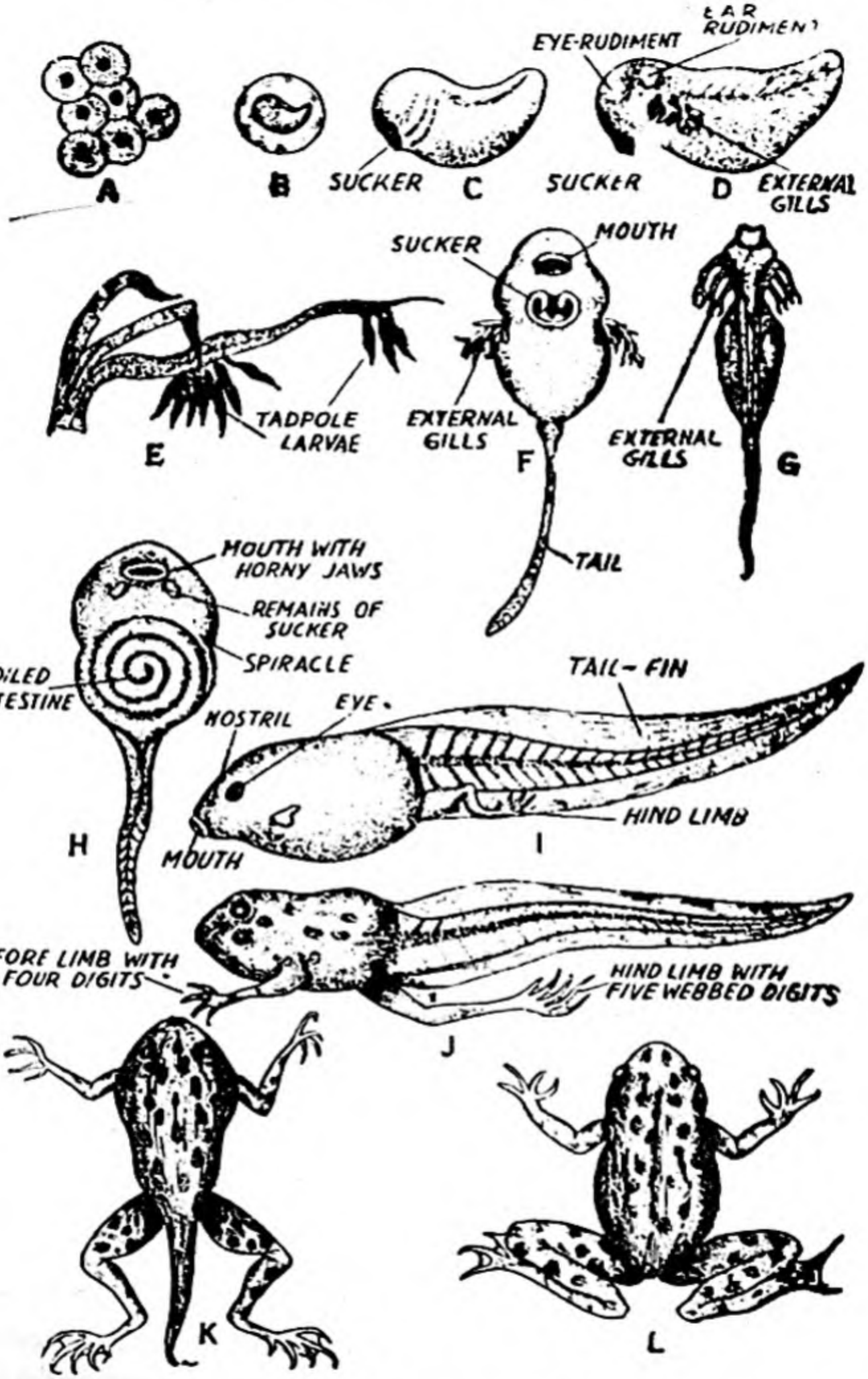


Fig 89. Larval development and metamorphosis of the frog. A, fertilized ova ; B-C, embryo before hatching ; D, newly hatched tadpole ; E, tadpoles attached to water-weeds ; F-G, tadpole with external gills (F, ventral view ; G, dorsal view) ; H, older tadpole ; I, development of hind-limbs ; J, development of fore-limbs ; K-L, assumption of adult form.

tadpole now respires just like a fish. The internal gills, like the external gills, are supplied with blood capillaries. The water enters the mouth and, after bathing the internal gills in the pharynx, passes into the branchial chamber through the gill-clefts, and finally goes out through the spiracle. The oxygen dissolved in the water is taken in by the blood in the gills and carbon dioxide is given out. In the meantime the two lungs are developed from two diverticula of the alimentary canal just behind the pharynx. For a short period the tadpole breathes both by the lungs and the internal gills. The limbs also by now have appeared. The hind-limbs alone are visible for a time as the fore-limbs are hidden under the operculum.

The tadpole now undergoes a remarkable series of changes by which it is transformed from the fish-like larva to the air-breathing adult. It ceases to feed. The fore-limbs emerge from beneath the operculum. The tail begins to shrink and its tissues break down, serving to build up other organs of the body. In other words, during the transition from a herbivorous to a carnivorous form, the larva feeds on its tail which ultimately disappears. The mouth becomes wide and loses the horny jaws and the papillae. The tongue grows in size and the teeth are formed. The gills become functionless, and finally disappear. The lungs become the main respiratory organs The intestine becomes shorter while the stomach and the liver become larger, and the animal becomes carnivorous. The series of striking changes which the larva undergoes to assume the adult form is called *metamorphosis*.

Significance of Metamorphosis. The animal kingdom consists of a great variety of organisms which may be arranged in a more or less regular gradation from the simplest to the most complex types. It is now universally admitted that all these animals did not come into being at once but descended or *evolved* from other simpler animals, which existed before them,

in the course of ages by gradual steps. This process is known as *organic evolution*. Evidence in support of this doctrine is furnished by the study of embryology. It has been observed that the larval stage in many animals possesses characters which are found in the adult stage in animals of a lower grade. A good example of this is the tadpole larva of the frog. It resembles a fish in possessing a tail and gills, and in its mode of life. Why should the tadpole pass through a fish-like stage in its life-history ? It is because the frog is evolved from a fish-like ancestor and it passes in its own life through stages which are found in its evolutionary history. The development of an individual animal is known as *ontogeny* and the ancestral history of the race as *phylogeny*. We may, thus, say that in the frog "Ontogeny repeats phylogeny" This theory is known as the *recapitulation theory* or *biogenetic law*.

CHAPTER XVIII

AMOEBA

General Features. The common amoeba, *Amoeba proteus*, is the simplest of all the living animals. It is a unicellular organism found in fresh water ponds and streams in the mud at the bottom or adhering to weeds, stones or other submerged objects. As it is only about 0·25 mm. in length, it is not visible to the naked eye and a microscope has to be used to examine it. Ordinary pond-water does not generally contain amoebae in sufficiently large numbers so they are obtained, for study, from a *culture* made in the laboratory. For this purpose a small quantity of hay or wheat, or a few dry leaves, are placed in water in a dish which is left uncovered in an airy room. By the action of bacteria the organic matter in the dish breaks down and a rich nutritive infusion is formed. The process is hastened if warm water is used or if the dish is put out in the sun for the first few hours. Amoebae appear in large numbers in the dish within two or three days. They, as also the bacteria, arise from tiny spores, which are found floating in the air from where they settle down on the dish. Amoebae are particularly abundant in the scum on the surface of water in the dish. A little of this scum should be spread out on a slide in a drop of water and, after putting on a cover-slip, examined under the microscope, at first under the low power and then under the high power. As amoebae are more or less transparent they become invisible in strong light. It is, therefore, necessary to reduce the amount of light passing through the slide.

Structure. Under the low power of the microscope *Amoeba* (Fig. 90) appears as an irregular, almost colourless speck of

jelly. At first sight it appears motionless but very soon it is found to slowly change its shape by putting out finger-like

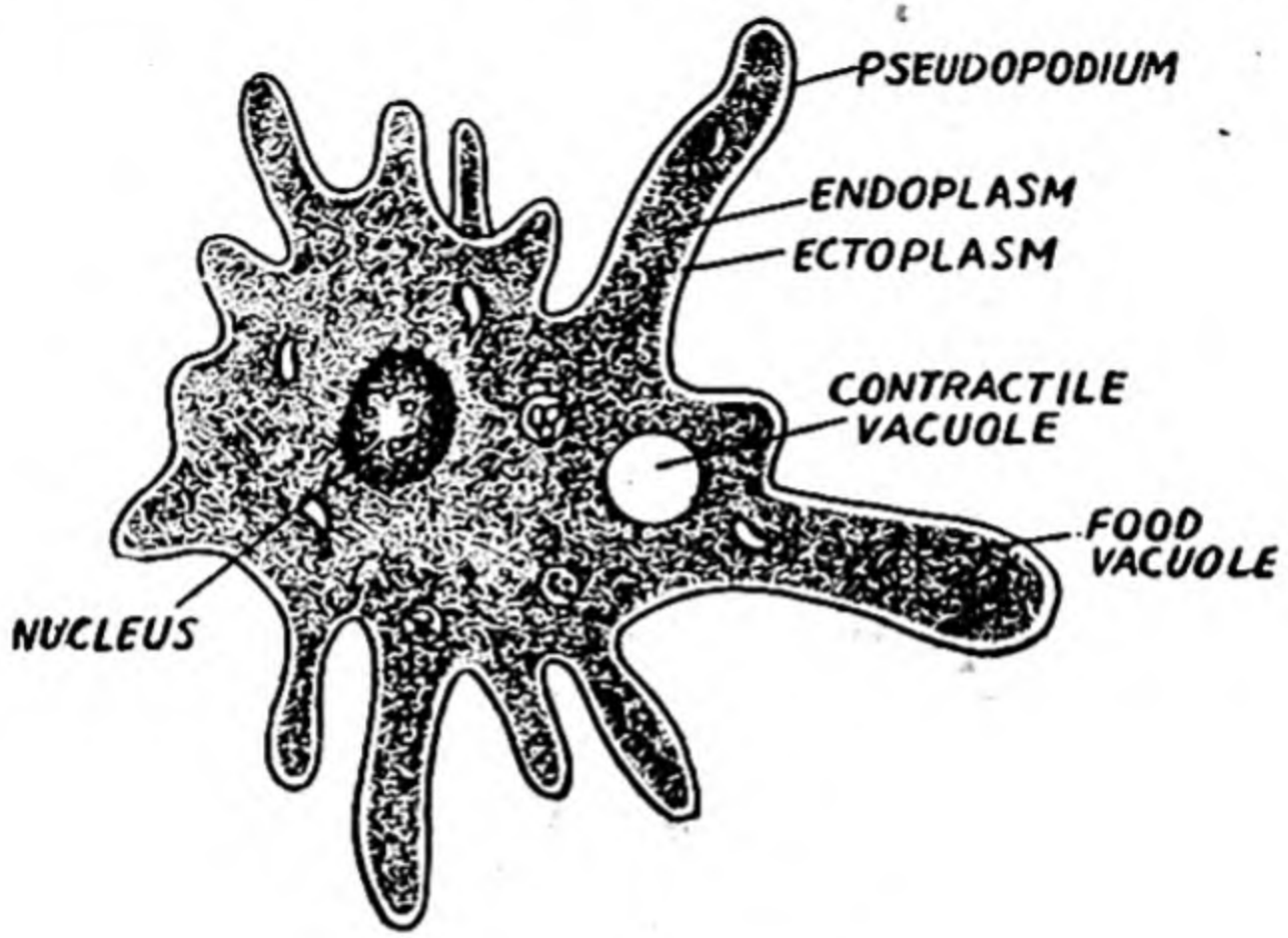


Fig. 90. *Amoeba proteus.*

processes in one direction and withdrawing others from the opposite direction. These processes are known as *pseudopodia*, meaning false feet.

Under the high power of the microscope the cytoplasm is seen to consist of an outer clear and relatively firm *ectoplasm* and an inner granular and more fluid *endoplasm*. The endoplasm contains in the centre a round nucleus which is difficult to see in the living amoeba. When stained with acetic methyl green the nucleus is seen to possess a nuclear membrane within which are present granules of chromatin. A clear bubble-like body, visible in the living amoeba, is known as the *contractile vacuole*. It appears and disappears more or less at regular intervals. A number of *food vacuoles*, of varying sizes, may

often be seen in the cytoplasm. They contain food particles, and are temporary and non-contractile.

Physiology. Although *Amoeba* is a unicellular organism it exhibits all the activities of higher animals in its own simple way, within the boundaries of a single cell. It moves about, ingests and digests food, excretes waste products, respires, reproduces itself and responds to changes in its environment. It is not provided with special organs for discharging these functions which are performed, as we will presently see, by the nucleus and the cytoplasm which constitute its single-celled body.

Locomotion. Locomotion in *Amoeba* is effected by putting out pseudopodia in the direction of the movement and withdrawing others from the opposite direction. A *pseudopodium* is formed by the projection, from the surface, of a blunt process consisting of ectoplasm, and the granular endoplasm flowing into it. *Amoeba*, thus, creeps along by thrusting out pseudopodia and then flowing into them. These flowing movements are known as *amoeboid movements.* We have already seen that amoeboid movements are performed by the leucocytes which move from place to place in the body by means of their pseudopodia.

Nutrition. The food of *Amoeba* consists of microscopic plants or diatoms, tiny fragments of algae, various unicellular organisms and bits of dead organic matter. When *Amoeba* comes in contact with one of these it extends its pseudopodia which flow round the former. Gradually the food particle is fully engulfed or *ingested* (Fig. 91). *Amoeba* exhibits choice in the selection of food which may be taken in at any point on the cell surface. Inside the cell it becomes enclosed in a non-contractile cavity, the *food vacuole*, filled with water. Digestive fluids or *enzymes* are secreted into the food vacuole by the surrounding cytoplasm. By the action of the enzymes the food is converted into a diffusible form or is *digested*. The undigested

part is passed out or *egested* at any point on the surface. The process actually consists of the organism moving away leaving the undigested material behind. *Amoeba* can digest proteins and probably also fats and sugars but not starch. The digested food is absorbed into the cell by diffusion and then assimilated or converted into living protoplasm. It should be noted that digestion in *Amoeba* takes place inside a cell (*intracellular*) and not in a cavity enclosed by cells (*intracellular*).

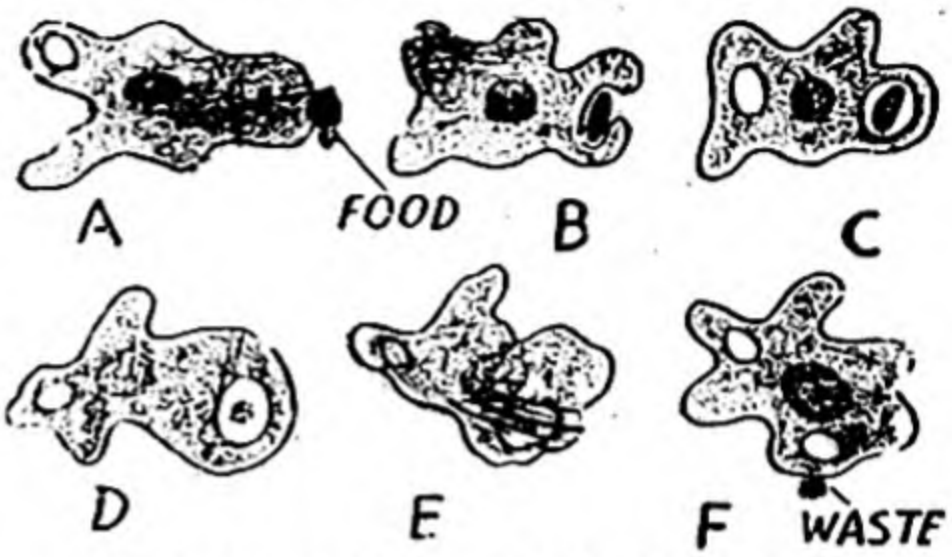


Fig. 91. Ingestion of food in *Amoeba*. (From Spratt)

Respiration and Excretion. Respiration in *Amoeba* is carried on by the absorption of oxygen, dissolved in the surrounding water, through its general surface. The protoplasm, on oxidation, breaks down into simpler compounds liberating energy which the animal utilizes for its various activities, and forming waste products, including carbon dioxide and urea. Excretion of the waste products takes place mainly by diffusion through the general surface of the body.

It is believed that the contractile vacuole also serves as an excretory organ but direct evidence in support of this view is lacking. The chief function of the contractile vacuole probably is to regulate the quantity of water in the cell. The excessive amount of water, including that from the food vacuoles, is thus eliminated. The contractile vacuole is formed by the fusion of minute droplets, and at each contraction, bursts at the surface, discharging its contents into the surrounding water.

Behaviour. Although *Amoeba* does not possess a nervous system or sense-organs it responds to external stimuli in a more

or less definite way. It discriminates between a food particle and a grain of sand. It moves away from strong light. It responds negatively to strong chemicals. A creeping amoeba avoids an obstruction placed in its way but a floating amoeba tries to cling to a solid object with which it comes into contact. An electric current passed through a drop of water containing amoebae will cause the organisms to contract into globular masses as if to avoid the danger. The responses of amoeba to external stimuli, thus, are all such as to be beneficial to the individual.

Reproduction. When *Amoeba* has grown to its full size it *reproduces* itself by the asexual process of *binary fission* (Fig. 92). The organism assumes a spherical form with short pseudopodia. It then elongates and a constriction appears in the middle, which deepens and finally divides the cell-body into two. The nucleus, in the meantime, has divided into two by mitosis. The two daughter amoebae, thus, come to have one nucleus each. The process of binary fission is repeated by each succeeding generation. In this way hundreds of amoebae may be produced, in few days, from a single parent amoeba. It is, thus, clear that

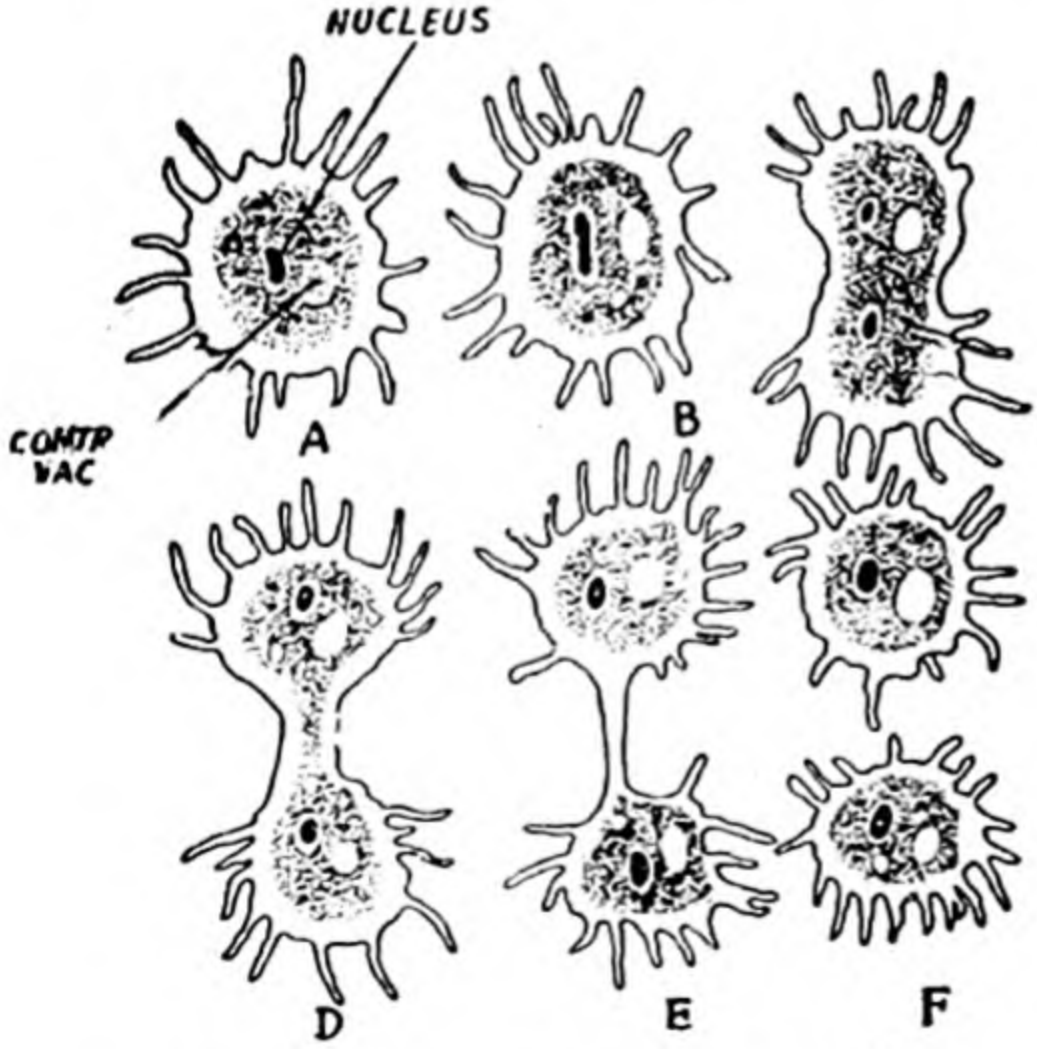


Fig. 92. Binary fission in *Amoeba*.

there is no natural death in this animal and, except for accidental death, it may be considered as immortal.

Amoeba under unfavourable conditions, such as the drying up of the water in which it lives, becomes encysted and undergoes *multiple fission* or *sporulation* (Fig. 93). It withdraws its pseudopodia and becomes a globular mass. A resistant envelope or *cyst* is secreted round the body. The nucleus divides into a large number of daughter nuclei which migrate towards the periphery. Each daughter nucleus becomes surrounded by a mass of protoplasm. In the encysted condition these little amoebae are able to withstand the effect of prolonged drought. The cysts may lie in the dry mud till the return of water or, as is more likely to happen, they may be blown away by the wind along with the dust particles to another piece of water. Here by the effect of moisture the cyst-wall breaks and the tiny amoebae or *spores*, with narrow pointed pseudopoia, are set free. They then grow up into full-sized amoebae. It is from the cysts floating in the air that we get active forms in our laboratory culture of *Amoeba*.

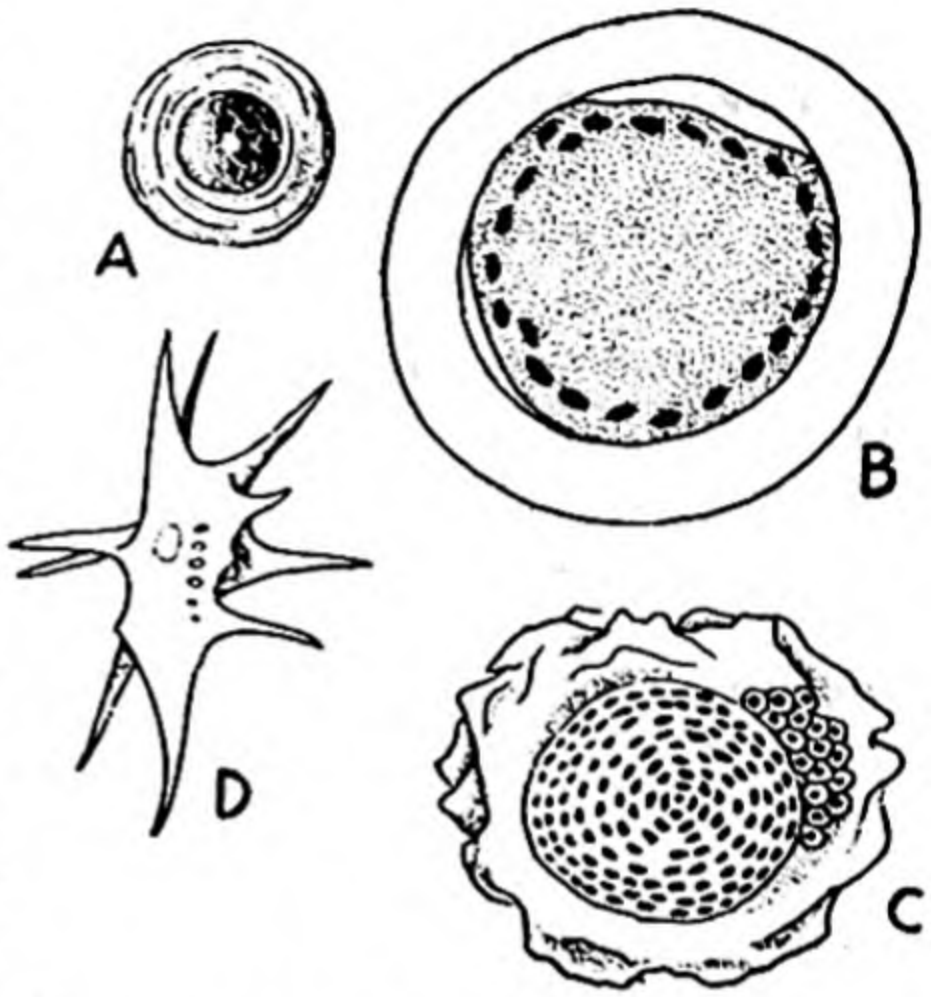


Fig. 93. Multiple fission in *Amoeba*. A, encysted amoeba ; B, section of the cyst ; C, surface view of the cyst ; D, spore. (From Borradaile after Scheel).

CHAPTER XIX

PARAMECIUM

General Features. *Paramecium caudatum* is a unicellular fresh water organism. It is commonly found in ponds with weeds growing in them. But cultures of *Paramecium*, like those of *Amoeba*, may be prepared in the laboratory by keeping in a warm place infusions of hay, dry leaves or wheat grains, made with ordinary tap water. Another simple way to prepare a culture is to place submerged water weeds in a jar containing pond water. The stale water of vases, after flowers have stood in them for some days, generally contains paramecia in large numbers. Although no original account of cyst formation in *Paramecium* seems to be available the appearance of organisms in infusions justifies the assumption that cysts do exist.

Paramecium measures up to 0·3 mm. in length and is just visible to the naked eye as a whitish speck. It is, therefore, of a very convenient size for microscopic study. But the animalcules swim about so rapidly that a study of their structure under the microscope becomes impossible. Their movement can, however, be checked by placing a few fibres of cotton wool in the drop of water containing the organisms. Another method to slow down their movements is to narcotize them by placing a minute drop of 1% solution of cocaine hydrochloride near the edge of the cover-glass and letting it diffuse slowly under the latter.

Structure. *Paramecium* (Fig. 94) differs from *Amoeba* in having a definite shape, which is somewhat like a slipper. It is, therefore, popularly known as the "slipper-animalcule". Its body is elongated with a broad rounded anterior and a somewhat pointed posterior end. Its ventral surface is flattened

while the dorsal surface is slightly convex. The entire surface of the body is covered with small processes, the *cilia*, arranged

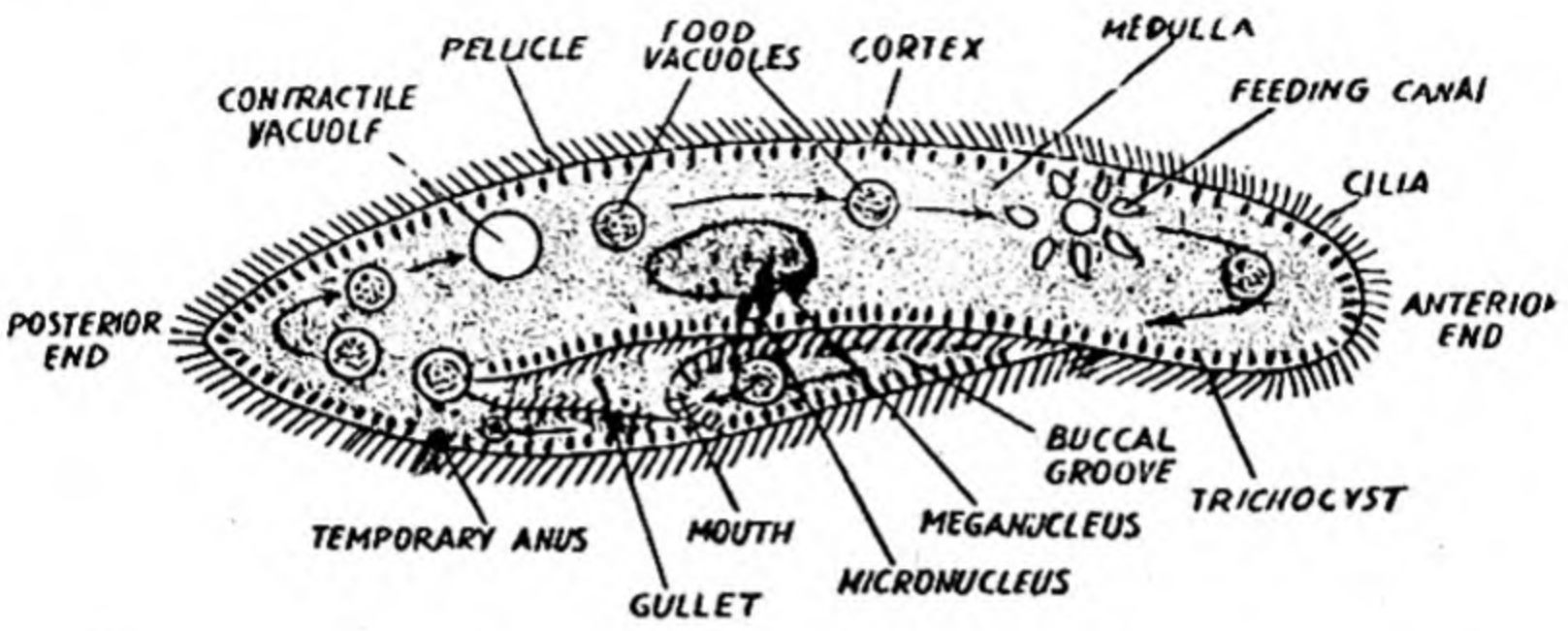


Fig. 94. *Paramecium caudatum.*

in longitudinal rows except at the anterior end where they follow a spiral path. On the ventral surface there is an oblique groove, the *buccal* or *oral groove*. It begins at the anterior end, on the left side and, curving inward to the middle line, opens into the *mouth* or *cytostome* a little behind the middle of the body. The mouth leads into a funnel-shaped *gullet* or *cytopharynx* which passes directly into the cytoplasm of the cell. The cilia lining the gullet are stouter than those covering the body and are fused to form an *undulating membrane*.

The cytoplasm ; as in *Amoeba*, is differentiated into an outer clear *ectoplasm* or *cortex* and an inner granular *endoplasm* or *medulla*. The *cortex* is covered by a firm but flexible membrane, the *pellicle*. It gives the animal its definite form. The pellicle (Fig. 95) shows hexagonal depressions bounded by ridges. From the centre of each depression projects a cilium which originates in the cortex from a granule, the *basal granule*. Each cilium consists of an axial thread surrounded by a sheath which is continuous with the pellicle. The basal granules are connected with one another by longitudinal fibrils known as

the *interciliary fibrils*. The granules and the fibrils constitute the *neuromotor system* which serves to co-ordinate the movements of the cilia. The cortex appears striated due to the presence in it of spindle-shaped bodies, the *trichocysts*, which have their long axes perpendicular to the surface. The trichocysts are capable of being discharged to the outside through apertures in the pellicle ridges. Two *contractile vacuoles* are present in the cortex on the dorsal side, one toward each end of the cell-body.

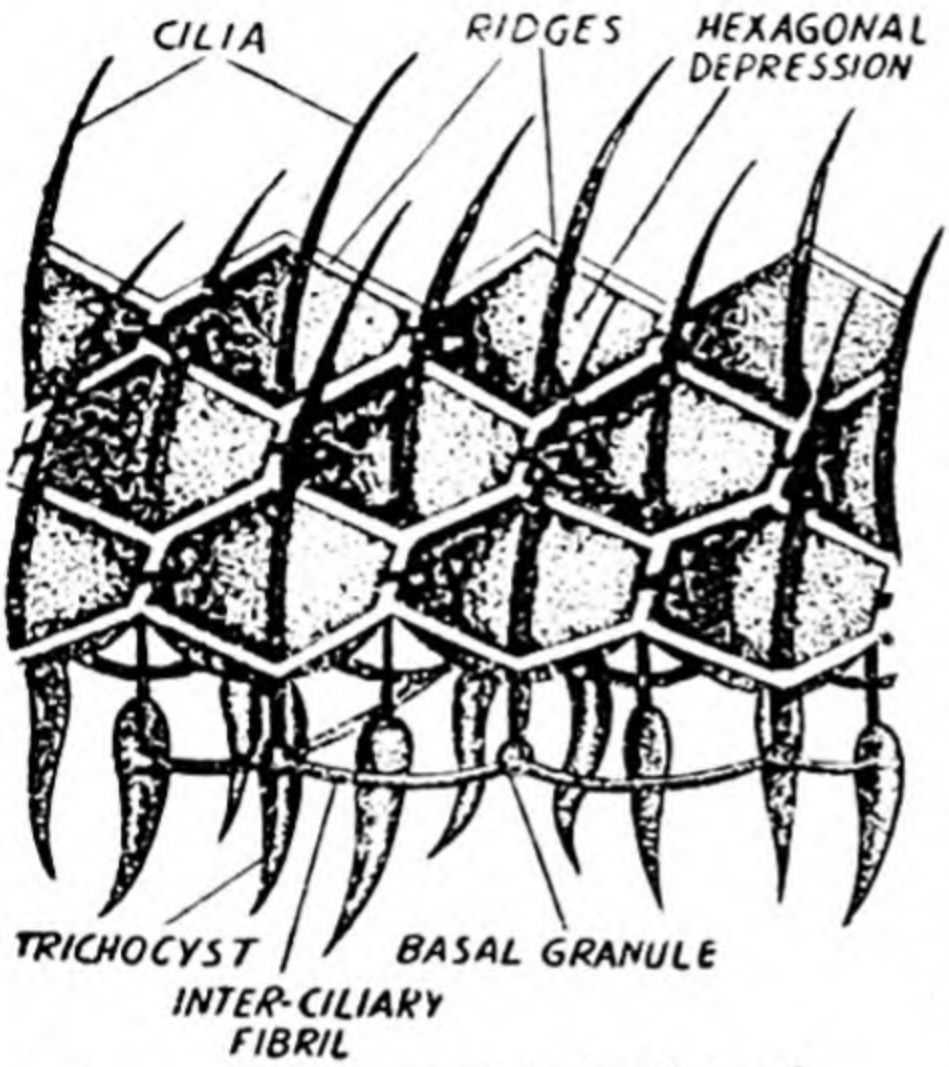


Fig. 95. Structure of the pellicle of *Paramecium*. (After Lund).

The *medulla*, which is the more fluid part of the cell-body, contains the nuclear apparatus and the food vacuoles. The nuclear apparatus lies in the middle of the body and consists of two nuclei which differ from each other both in size and function. One of them is large and oval, and is known as the *meganucleus* or *macronucleus* while the other is small and spherical and is called the *micronucleus*. The latter lies in a depression on the surface of the former. The meganucleus governs the ordinary life processes or vegetative functions of the animalcule and is, therefore, known as the *vegetative nucleus*. During the reproductive act of conjugation the meganucleus disappears and the micronucleus becomes very active and plays an important role in the process. The micronucleus is, therefore, also known as the *generative nucleus*.

Locomotion. *Paramecium* swims by means of the cilia. When these beat backward the body is pushed forward. Due to the oblique strokes of the cilia the body, as it goes forward, rotates upon its own longitudinal axis. At the same time the cilia in the buccal groove beat more vigorously than others so that the anterior end swerves to the aboral side. But as the body itself is rotating the swerving takes place alternately to the right and the left sides. The result is that the animal moves forward along a spiral path which has a straight axis (Fig. 96). If, when swimming forward, the animal is obstructed by a solid object it moves back a little, turns to one side and goes forward at an angle to the original path. This is repeated, if necessary, till a clear path is found.

Fig. 96. *Paramecium* swimming along a spiral path. (From Hegner)

Nutrition. The food of *Paramecium* consists of bacteria and other small organisms which are swept into the mouth by the current of water set up by the beating of cilia in the buccal groove. The vibrations of the undulating membrane drive the food to the posterior end of the gullet along with some water. Here the food particles become enclosed within a droplet of water forming a food vacuole, which constricts off and starts circulating in the endoplasm. A new food vacuole now begins to be formed in its place so that a number of them may be present at a time in the endoplasm. By the streaming movement of the endoplasm the food vacuoles are carried round along a definite path. This process is known as *cyclosis*. The course followed by the food vacuoles begins just behind the gullet, runs backward to the posterior end, then forward to the

anterior end and finally backward and downward to finish on the ventral surface below the starting point. During this journey the food is digested by the enzymes secreted into the vacuoles by the surrounding protoplasm. It is believed that *Paramecium* can digest proteins and starch but not fats. The cyclosis undergone by the food vacuoles ensures an even distribution of digested food to all parts of the body. The digested food is absorbed by the cell by diffusion and built up into protoplasm. The undigested material is discharged from the body through a temporary anus or *cytopyge* formed only when required, below and a little behind the posterior end of the gullet.

Respiration. As in *Amoeba*, respiration takes place through the general surface of the body. The oxygen dissolved in the surrounding water is absorbed by the pellicle and it slowly diffuses throughout the cell-body. Carbon dioxide, likewise, passes out of the body through the general surface.

Excretion. Nitrogenous waste products, such as urea and ammonia, are eliminated from the body by the two contractile vacuoles. The latter also regulate, as in *Amoeba*, the water content of the body. Water, containing nitrogenous waste products, is collected from the cytoplasm by six to ten pear-shaped radiating canals which surround each vacuole and discharge into it. The canals are, therefore, known as *feeding canals*. When the vacuole has reached its maximum size (*diastole*) it undergoes contraction (*systole*) and empties itself to the outside, probably through a pore in the pellicle. Immediately after this the feeding canals, which had disappeared at the time of diastole. reappear as mere streaks but soon swell up into pear-shaped bodies. In the meantime a new vacuole has begun to be formed in the centre of the feeding canals and the whole process is repeated. The two vacuoles do not contract together but alternately at intervals of ten to twenty seconds.

Offence and Defence. The trichocysts are generally regarded as organs of offence and defence. When the animal is irritated the trichocysts explode into long threads which are likely to confound the enemy and also provide the body with a protective covering of threads. The exploded trichocysts are replaced by new ones. It has been suggested that the trichocysts serve as organs of adhesion. As their tips are sticky the animal is able to attach itself to a solid object.

Reproduction. *Paramecium* reproduces itself by binary fission interrupted, occasionally, by a temporary union or *conjugation* of two individuals during which there is mutual exchange of nuclear material.

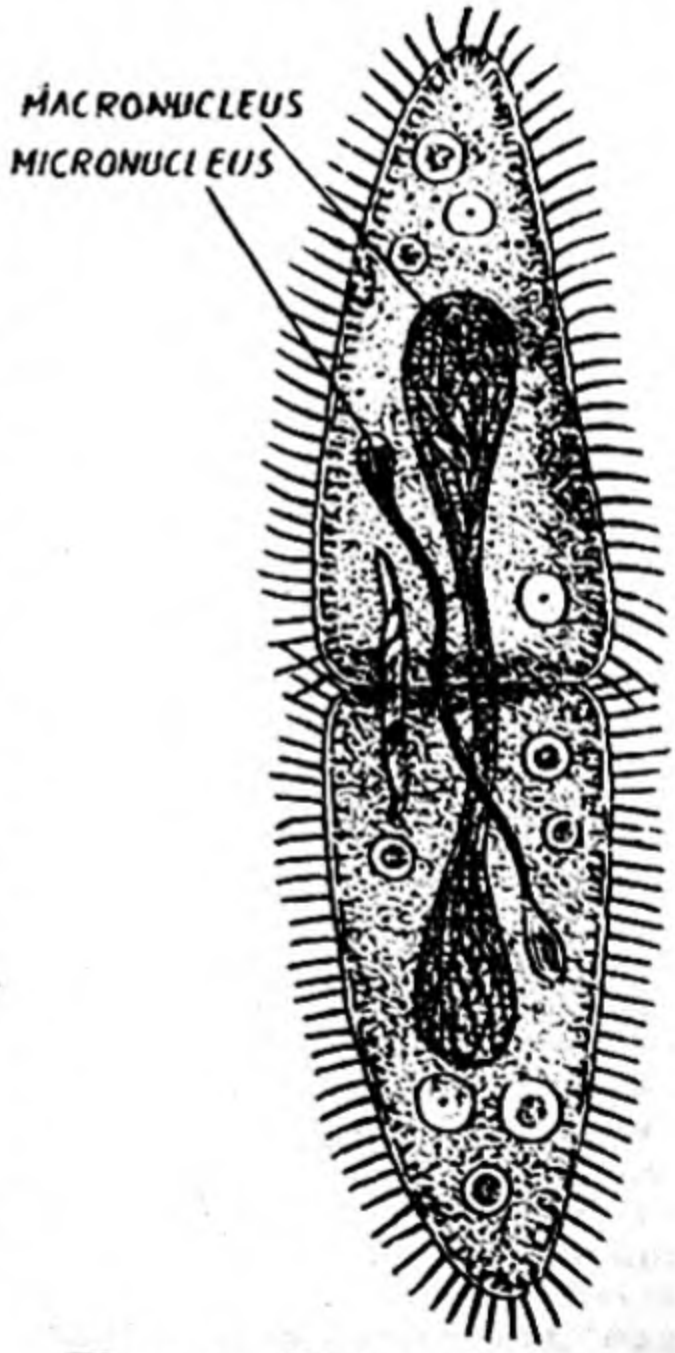


Fig. 97. Binary fission in *Paramecium caudatum.*

In *binary fission* (Fig. 97) the animal divides transversely. The micronucleus divides first by a kind of mitosis. The two daughter nuclei move apart and come to lie one near each end of the body. The meganucleus elongates and divides transversely by amitosis. A new gullet begins to be formed from the old one by budding and two new contractile vacuoles make their appearance. While these changes are taking place a transverse constriction or cleavage furrow appears round the middle of the body. The furrow gradually deepens till the body of the animal is completely divided into two. Each daughter paramecium has a micronucleus and a

meganucleus. The missing parts of the body are developed and the young paramecia grow to full size.

During *conjugation* (Fig. 98) two individuals, known as *conjugants*, come together and adhere to each other by their

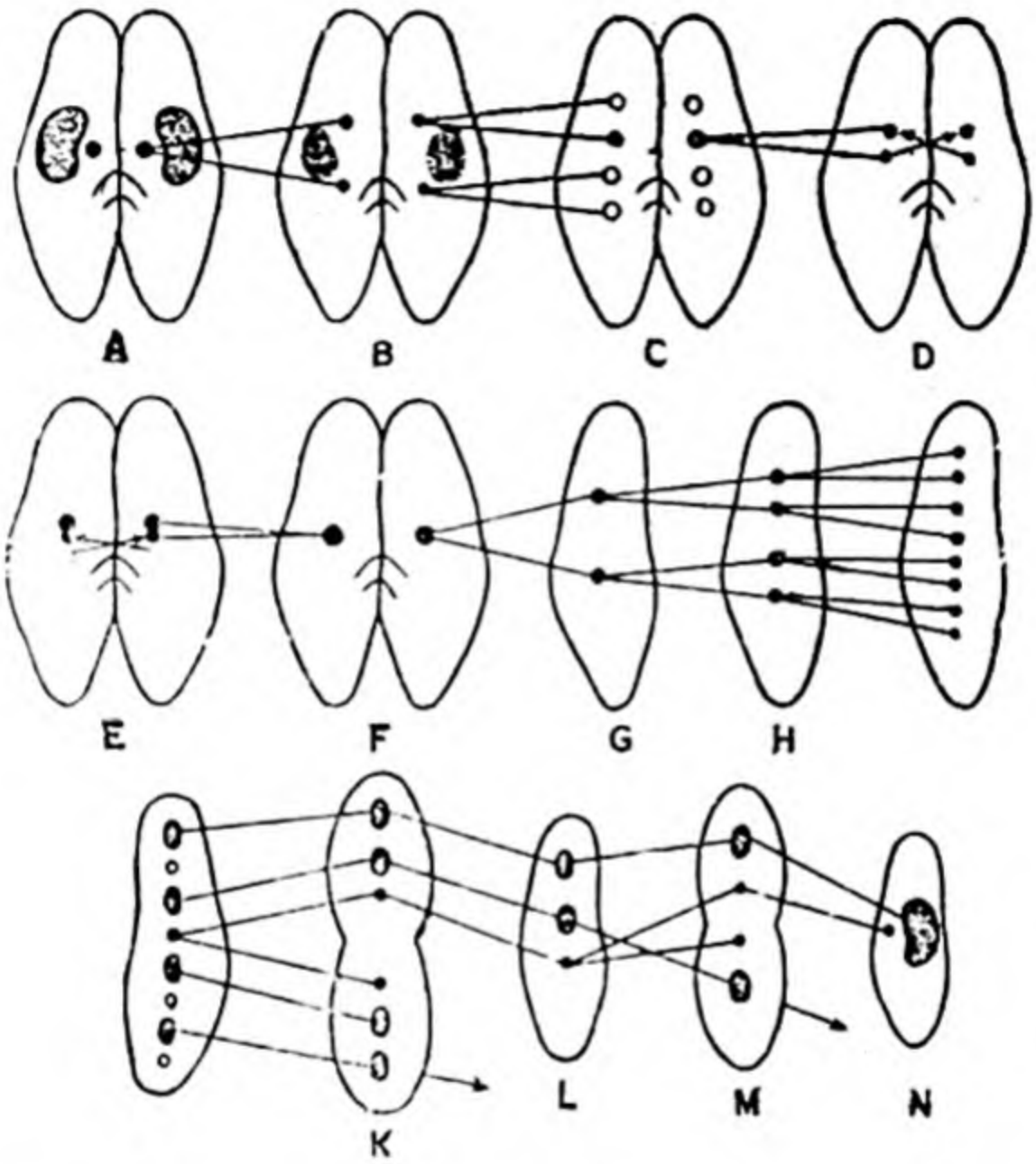


Fig. 98. Conjugation in *Paramecium caudatum*. A, conjugating pair; B, meganucleus breaks down, each micronucleus divides; C, each micronucleus divides again, three out of four disappear; D, each micronucleus divides unequally; E, smaller (migratory) pronucleus of each conjugant crosses over into the other; F, migratory and stationary pronuclei fuse and conjugants separate (only one exconjugant shown in G); G-I, fusion nucleus divides three times to form eight micronuclei; J, four micronuclei enlarge into meganuclei and three micronuclei disappear; K, remaining micronucleus divides and exconjugant divides; L, each daughter organism has two meganuclei and one micronucleus (only one daughter shown); M, micronucleus divides and organism divides; N, each daughter has one meganucleus and one micronucleus (only one daughter shown).

ventral surfaces. A protoplasmic bridge is formed between them in the region of the gullet. During conjugation the pair continues to swim about. The nuclei now pass through a series of remarkable changes. The meganucleus of each conjugant begins to disintegrate and eventually disappears into the cytoplasm. The micronucleus, on the other hand, shows great activity. It divides twice by mitosis to form four micronuclei in each conjugant. These divisions are believed to result in a reduction of the number of chromosomes to one half and may, thus, be compared to the maturation divisions of the metazoan germ cells. Three out of the newly formed micronuclei disappear. The fourth again divides into two unequal gametic nuclei or *pronuclei*, namely, a small *migratory* male pronucleus and a large *stationary* female pronucleus. The migratory pronucleus of each conjugant then crosses over into the body of the other conjugant and fuses with its stationary pronucleus. Each conjugant is now a zygote for its nucleus has been formed by the fusion of the male and female pronuclei. Such fusion of nuclear material from two different individuals is known as *amphimixis*.

After the exchange of nuclear material the conjugants separate and are now known as *exconjugants*. The fusion nucleus of each exconjugant divides three times successively to form eight micronuclei. Four of these enlarge to become meganuclei and three of the others degenerate. The exconjugant has now four meganuclei and one micronucleus. The micronucleus divides and the exconjugant undergoes binary fission so that each daughter organism has two meganuclei and one micronucleus. The micronucleus divides again and the organism undergoes binary fission for the second time. The result is that from each exconjugant four young paramecia are produced, each containing one meganucleus and one micronucleus.

Significance of Conjugation. Is has been observed that paramecia are unable to go on multiplying indefinitely by binary fission. Sooner or later the process stops and a period of depression sets in. The organisms do not grow to their full size and become inactive. They become, so to say, old and show signs of decay. Conjugation at this time rejuvenates them. They regain their lost vitality and become young and active again. They are able to divide normally by binary fission. As conjugation involves the fusion of nuclear material from two different individuals, it furnishes a mechanism for variation and heredity. It may, thus, be compared to fertilization in the higher animals.

Endomixis. Experiments have shown that poor conditions of life induce the process of conjugation and that by providing nourishing food and regularly changing the medium in which paramecia are kept, the organisms can be maintained in young and active condition, without recourse to conjugation, for exceedingly long periods. By this method Woodruff was able to produce, in twenty years, over twelve thousand generations of *Paramecium aurelia*, all healthy and active, without the intervention of conjugation. He, however, discovered that whenever depression set in, it was overcome by the animal by an internal process of reconstruction of the nuclear apparatus. He named this process *endomixis*. During endomixis the meganucleus disintegrates and disappears, and the micronucleus behaves more or less as in conjugation. There is, of course, no exchange of nuclear material, but only its reorganization. It, thus, appears that reconstruction of the nuclear apparatus, after a certain period, becomes necessary for the maintenance of normal health and vitality of the organism.

CHAPTER XX

THE MALARIAL PARASITE

General Features. The *malarial parasite* is a unicellular organism causing malaria in man. Its life-history consists of two cycles, one of which is passed in the human blood and the other in the stomach of the mosquito. An organism of this kind which lives on or within another organism, at the expense of the latter, is known as a *porasite*. The organism at whose expense the parasite lives is known as the *host*. In the case of the malarial parasite there are two hosts, namely, man and mosquito. In man the parasite causes recurring attacks of fever, anaemia and, in chronic cases, enlargement of the spleen, but it apparently does no harm to the mosquito.

Of the two cycles in the life-history of the parasite one, which is passed in the blood of man, is asexual, and the other, which is passed in the stomach of the mosquito, is sexual. The asexual and the sexual cycles alternate with each other. This phenomenon is known as *alternation of generations*. As the parasite undergoes sexual differentiation in the mosquito, the latter is known as the *primary host* and man as the *secondary* or *intermediate host*. We thus see that, in addition to alternation of generations, there is also alternation of hosts in the life-history of the malarial parasite.

The malarial parasite has been placed in the genus *Plasmodium* which includes three distinct species producing different types of human malaria.

Plasmodium vivax causes tertian malaria characterized by an attack of fever every forty-eight hours, *Plasmodium malariae* causes quartan malaria in which fever recurs every seventy-two hours and *Plasmodium falciparum* causes quotidian,

tertian or irregular fever. In quotidian malaria the fever is more or less constant. The tertian malaria caused by *P. vivax* is of a mild type and is seldom fatal. It is, therefore, known as *benign tertian.* In the case of *P. falciparum*, on the

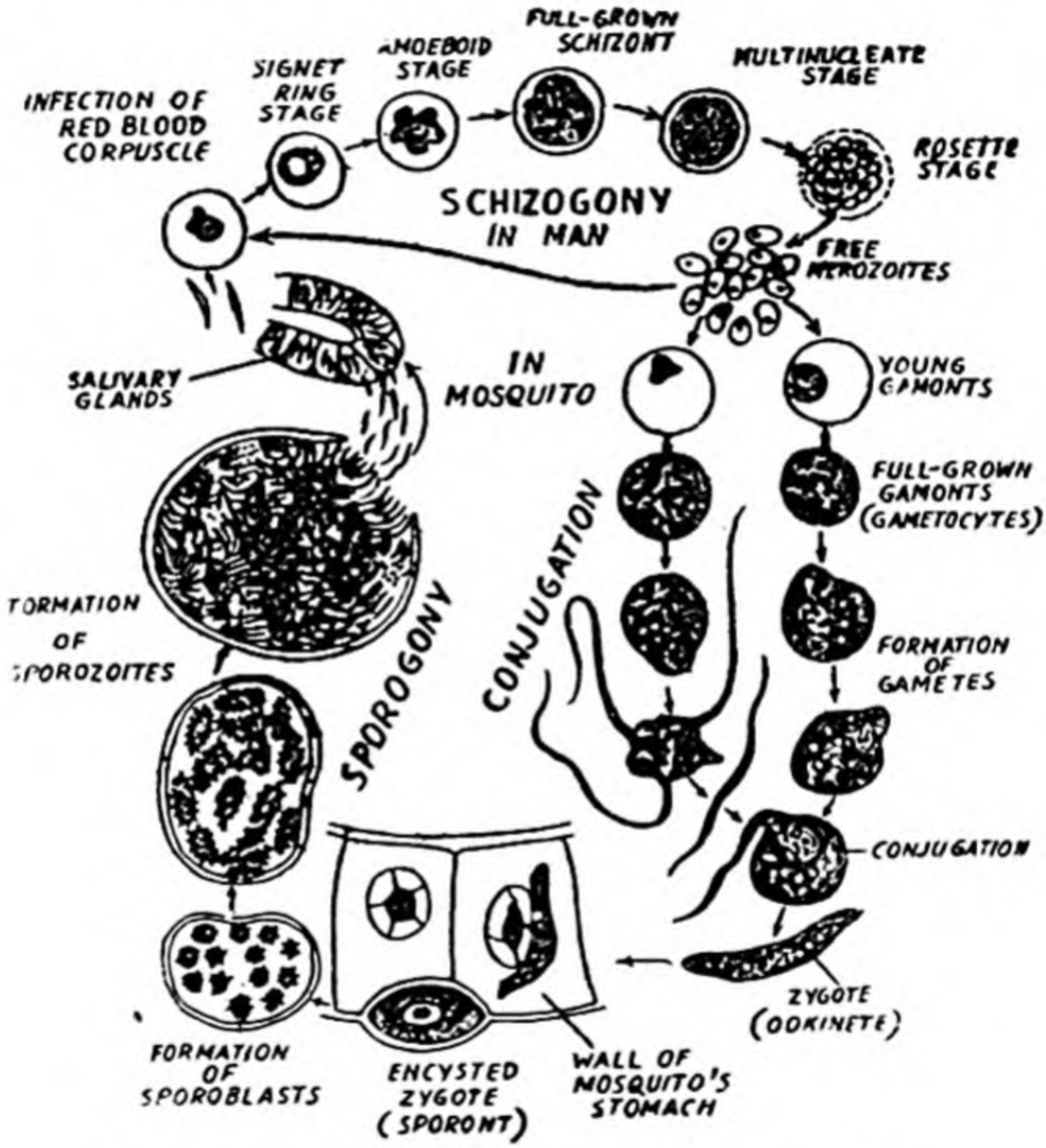


Fig. 99. Life-history of *Plasmodium vivax.*
(After Borradaile).

other hand, it is of a virulent type showing high death rate. It is, therefore, called *malignant tertian.* The life-histories of the three species of *Plasmodium* differ very slightly from one another.

Life-cycle in Man. When an infected female mosquito of the genus *Anopheles* bites a healthy person for obtaining blood it introduces, along with the saliva, a large number of parasites, known as *sporozoites*, into the blood stream. The male does not suck blood but lives on plant juices. Each sporozoite is a slender curved body tapering at the two ends and containing a nucleus in the middle. Its cuticle is firm but elastic. It was formerly believed that the sporozoites, after being injected into the blood stream, immediately entered the red blood corpuscles. However, there is now evidence to show that the sporozoites, within a short period after injection, disappear completely from the blood and pass into the tissue-cells of the liver. Here they grow and multiply. This stage is known as the *pre-erythrocytic stage* (*erythrocyte* being another name for a red blood corpuscle). The parasites may now reinfect liver-cells (*exo-erythrocytic stage*) or may pass into general blood circulation and enter the red blood corpuscles (*erythrocytic stage*).

The parasite, after entering a red blood corpuscle, becomes rounded. A non-contractile vacuole is formed inside it giving it a ring-like appearance. This stage is known as the *signet-ring stage*. Soon the vacuole disappears and the parasite becomes amoeba-like, and grows at the expense of the red blood corpuscle. By means of its pseudopodia it ingests the cytoplasm of the corpuscle which is rich in haemoglobin. The latter is converted into a brown or black pigment, known as *melanin*, which is deposited in the cytoplasm of the parasite. During the growth period the parasite is known as a *trophozoite*. When full grown the trophozoite is spherical and occupies the greater part of the corpuscle. It now prepares to divide by multiple fission or *schizogony* and is, therefore, called a *schizont*. Its nucleus divides repeatedly till there are many daughter nuclei. These come to the surface and each becomes surrounded

by a portion of the cytoplasm so that minute unicellular bodies, known as *merozoites*, are formed. They become arranged like the petals of a rose and so this stage is known as the *rosette stage*. The unused cytoplasm of the schizont, containing all the melanin granules, collects in the centre of the rosette. The enfeebled corpuscle now ruptures and the merozoites along with the residual cytoplasm and the pigment are released into the plasma. The residual cytoplasm with the pigment is ingested by the leucocytes while each merozoite attacks a fresh red blood corpuscle and repeats the schizogonous cycle.

After a number of schizogonous cycles the parasites in the blood become so numerous as to produce symptoms of malaria. There is, thus, an interval of time between the first infection and the appearance of the symptoms of the disease. This interval, which in the case of malaria is about ten days, is known as the *incubation period*.

After the first attack of malaria the recurrence of fever coincides with the liberation of successive generations of merozoites into the plasma. That is why fever recurs every forty-eight hours in the case of *P. vivax* and every seventy-two hours in *P. malariae*. In the former the schizogonous cycle is completed in forty-eight hours and in the latter in seventy-two hours. In the case of *P. falciparum* the cycle varies so the fever recurs at irregular intervals. The chill and fever are due to the poisonous substances or *toxins* produced by the parasites and discharged into the blood by the rupture of infected corpuscles.

If the process of schizogony continues unchecked, a time will soon come when, owing to the destruction of the bulk of the red blood corpuscles, the life of the patient will be endangered. But the death of the host is not in the interest of the parasites as it will mean their own end, and the extinction of their race. It is, therefore, expedient that the parasites infect a new host. For this purpose some of the merozoites,

instead of growing into schizonts, become *gamonts* or *gametocytes*, that is, cells which will eventually develop into gametes. The gametocytes contain more melanin pigment than the schizonts. They are of two kinds, the male or the *microgametocytes* and the female or the *macrogametocytes*. In the microgametocyte the nucleus is relatively large with a loose texture, and the cytoplasm stains faintly. In the macrogametocyte the nucleus is small and compact, and the cytoplasm, being dense, due to the presence of reserve food material, stains deeply. The gametocytes of *P. vivax* and *P. malariae* are rounded while those of *P. falciparum* are crescent-shaped (Fig. 100). The gametocytes cannot develop any further in the human blood and perish unless they are taken in by the mosquito.

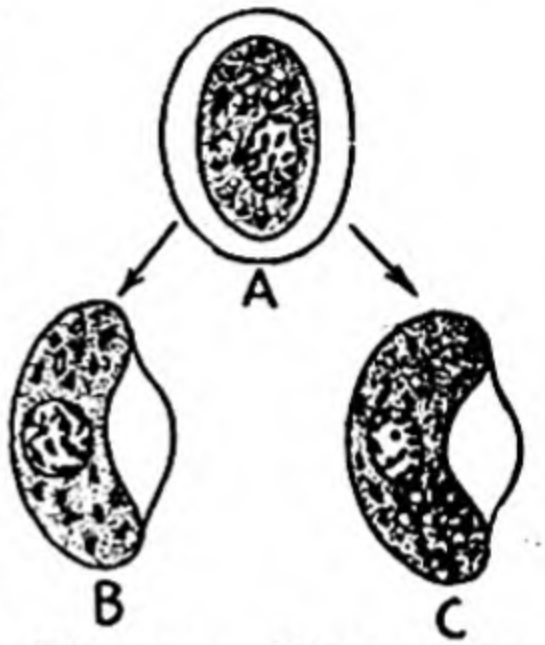


Fig. 100. *Plasmodium falciparum*.
A, young gametocyte; B, full-grown male gametocyte; C, full-grown female gametocyte, (After Borradaile).

Life-cycle in the Mosquito. When a female anopheline mosquito sucks the blood of a malarial patient it takes into its stomach the malarial parasites in various stages of development. Of these only the gametocytes develop further, the rest become digested. The gametocytes come out of the blood corpuscles by rupturing them. The nucleus of the microgametocyte divides into four to eight small nuclei which move to the surface of the cell. Then by an explosive process, known as *exflagellation*, long slender bodies shoot out from the surface, each consisting of a portion of the cytoplasm containing a nucleus. These are the residual body but soon become free and remain attached to the male gametes. For a time they swim about by lashing movements till they find a female gamete. In the macrogametocyte the nucleus probably gives

off one or two small bodies which may be compared to the polar bodies of the higher animals. The macrogametocyte by

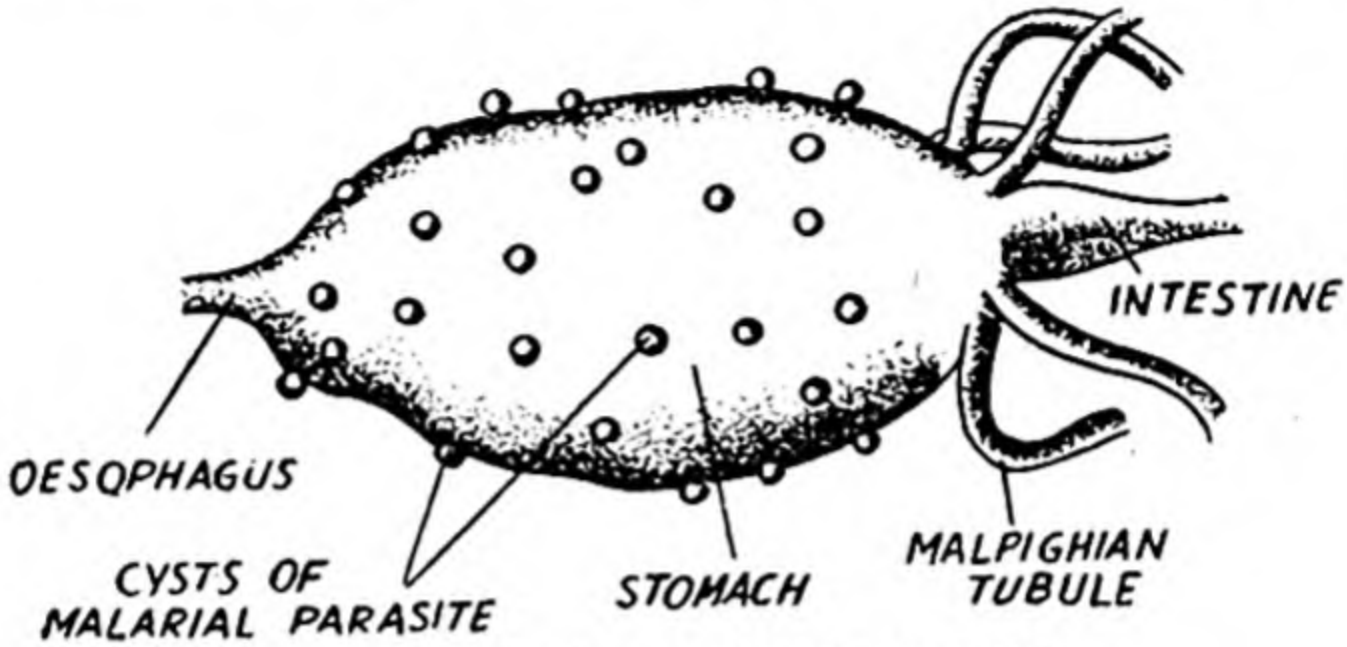


Fig. 101. Stomach of an infected mosquito.

this process becomes the female gamete. When a male gamete approaches a female gamete, the latter forms at the surface a small conical projection, the *cone of attraction*. The male gamete enters the female gamete through this cone. The male and the female pronuclei now fuse together and by the conjugation of the two gametes a zygote is formed. The zygote is at first rounded and inactive but soon changes into a motile worm-like organism known as *ookinete*. It penetrates the stomach wall and comes to lie under the outermost layer. Here it becomes spherical and secretes a pervious cyst round itself. These cysts appear as rounded projections on the wall of the mosquito's stomach (Fig. 101).

The encysted zygote is known as an *oocyst*. As it eventually gives rise to sporozoites, it is also known as a *sporont*. It grows in size by absorbing nutriment through the cyst wall. Its nucleus divides repeatedly and the resulting nuclei become surrounded by cytoplasm to form *sporoblasts*. From the surface of each sporoblast arise spindle-shaped protoplasmic processes. The sporoblast nucleus divides several times and each daughter nucleus passes into a protoplasmic process,

converting it into a *sporozoite*. The sporozoites, after some time become detached from the remains of the sporoblasts so that the oocyst becomes packed with bundles of sporozoites. Eventually the wall of the oocyst ruptures and liberates the sporozoites into the body-cavity of the mosquito. They move about in the body fluids till some of them find their way into the salivary glands. If the mosquito now bites a healthy person the sporozoites, along with the saliva, are injected into the blood and the schizogonous cycle is started again.

History of Discovery. At one time it was erroneously believed that malaria (*malo*, bad ; *aria*, air) was caused by bad air, but the true cause of the disease was later discovered by the combined efforts of a number of eminent workers. In 1880, Laveran, a French surgeon, was the first to discover the malarial parasites in the blood of a malarial patient. This was confirmed by Golgi and others but it was not known till then how the parasites found their way into the blood of man. The role of the mosquito in the transmission of the malarial parasites into the human body was first suggested by Patrick Manson. Working on this suggestion Ronald Ross, of the Indian Medical Service, carried out a series of experiments extending over two years, and in 1897 discovered cysts of the malarial parasite on the stomach of an anopheline mosquito wliich had been fed on the blood of a malarial patient. A year later he described the complete life-history of the bird malarial parasite. *Plasmodium praecox*, transmitted by *Culex fatigans*. In the meantime Grassi and his co-workers were successful in working out all the stages of the sexual cycle of the human malarial parasite in the anopheline mosquito. They, thus finally proved that parasites of human malaria were transmitted by *Anopheles*.

Control of Malaria. We have just learnt that the life-history of the malarial parasite, causing human malaria, is partly passed in the blood of man and partly in the mosquito. The measures to control malaria should be mainly directed

towards the destruction of the parasites both in man and the mosquito, and the prevention of mosquitoes from biting healthy person.

The life-history of the mosquito consists of four stages, namely, *egg*, *larva*, *pupa* and *imago* (adult). Of these the first three stages are passed in stagnant water. It is easier to destroy the early stages in water than to kill the flying adults. For this purpose kerosene oil, containing 5% D.D.T., should be sprayed over the surface of water to form a thin film. The larvae and pupae then find it impossible to breathe by bringing their air-tubes to the surface. As mosquitoes breed in water, the latter should not be allowed to collect near human dwellings. The mosquitoes can be prevented from biting healthy persons if the latter sleep inside mosquito nets, keep their arms and legs covered, particularly in the evenings, and smear the exposed parts of their bodies with "mosquito oil".

The parasites in the human blood can be killed by the use of *quinine* or by one of the synthetic drugs such as *atebrin*, *plasmoquine* or *paludrine*. Quinine and atebrin kill most of the schizonts but the gametocytes, particularly those of *P. falciparum*, are too resistant to be destroyed by these drugs. They may, thus, cure the patient but the latter may still have in the blood a large number of gametocytes which may be carried by the mosquito and cause malaria in other persons. Plasmoquine destroys the gametocytes and has only a mild effect on the schizonts Its effect, therefore. is complementary to that of quinine. Paludrine destroys all the stages of the malarial parasite in the blood of man, and, from this point of view, is the best remedy for malaria. Healthy persons should take small doses of quinine or atebrin daily as a prophylactic measure during the malarial season

CHAPTER XXI

HYDRA AND OBELIA

HYDRA

General Features. *Hydra,* commonly known as the *fresh water polyp,* is a small multicellular osganism found in ponds and streams containing clean water. If pond water along with weeds is placed in a jar or a dish and left undisturbed for some time, hydrae, if present, will appear as little whitish threads sticking by one end to the inner surface of the vessel or to the weeds. They are too small and inconspicuous to be easily detected by the naked eye and a pocket lens will be found useful when searching for them. On examination it will be seen that from the free end of each animal are given off a number of filamentous processes, the *tentacles.* The organism possesses remarkable power of contraction and extension. It may attain a length of half an inch with thin long tentacles or it may shrink to a globular mass with knob-like tentacles. There are several species of *Hydra* but three of them are more commonly known than others. *Hydra vulgaris* is more or less colourless and occurs throughout India, *Hydra fusca* is brownish in colour and is restricted to certain parts of India and *Hydra viridis* is of a bright green colour and has not so far been found anywhere in India.

External Characters. The body of *Hydra* resembles a hollow cylinder, closed at the proximal end by which it is attached to the substratum. This end is known as the *foot.* At the free or distal end there is a conical projection, the *hypostome,* having at its apex an aperture, the *mouth,* surrounded by a circlet of hollow tentacles. The cavities of the tentacles

are continuous with the cavity of the body or *enteron*, which communicates with the outside by the mouth. One or more

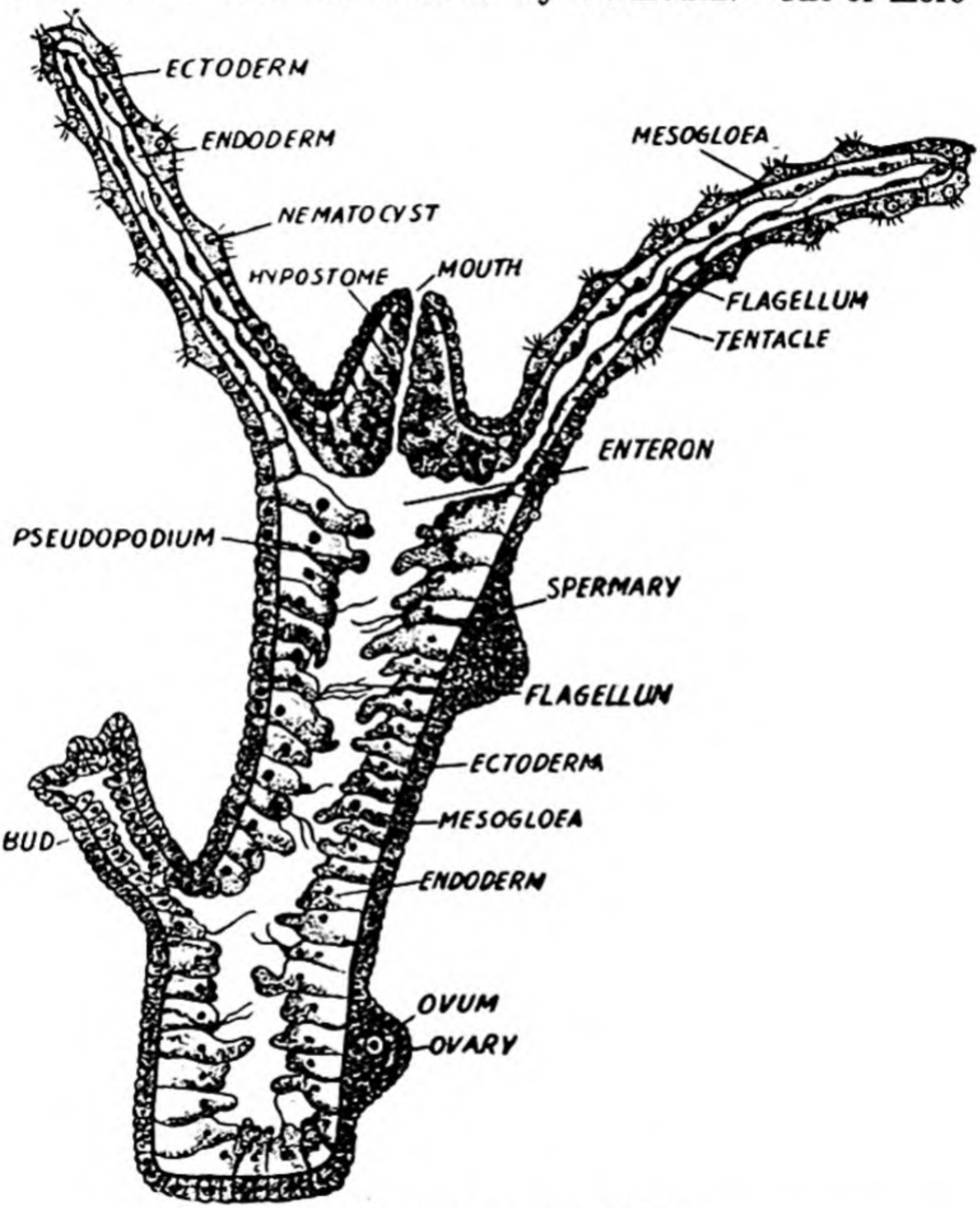


Fig. 102. Vertical section of *Hydra*.

small hydrae may be found growing from the surface of an adult *Hydra*. These are known as *buds*. They differ from the

parent only in size and in the incomplete development of the tentacles. *Hydra*, unlike the frog, is *radially symmetrical*, that is, any longitudinal section passing through the central axis will divide the animal into two similar halves.

Structure. The structure of *Hydra* can be made out by examining a vertical section (Fig. 102) under the microscope. The body of *Hydra* consists of two layers of cells arranged round the enteron. It is, therefore, a two-layered or *diploblastic* animal. The outer layer of cells is known as the *ectoderm* and the inner layer as the *endoderm*. Between the two layers is a non-cellular gelatinous membrane, the *mesogloea*. The arrangement of layers in the tentacles is the same as in the body.

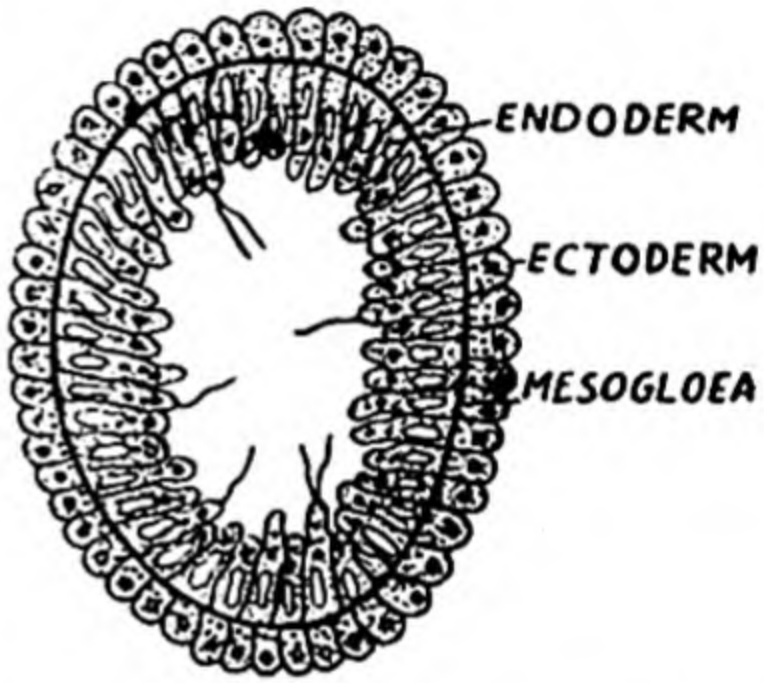


Fig. 103. Transverse section of *Hydra*.

The *ectoderm* (Fig. 104) consists of four kinds of cells, namely, (1) the epitheliomuscular cells, (2) the interstitial cells, (3) the cnidoblasts and (4) the nerve cells.

The *epithelio-muscle cells*, so called because they perform an epithelial as well as a muscular function, are large conical cells with their broad ends facing outwards and their narrow ends directed inwards. Each cell contains a large nucleus. Its inner narrow end is prolonged into one or more *muscle-processes* or *muscle-tails* which run along the length of the animal at right angles to the cell. The muscle-processes form, more or less, a continuous layer of longitudinal muscle fibres just outside the mesogloea. The muscle-processes possess a high degree of contractility and the ability of *Hydra* to contract into

a globular mass or expand into a long thread is chiefly due to their presence.

The *interstitial cells* are small cells filling up the spaces between the narrow ends of the epithelio-muscular cells. They are undifferentiated cells and, should occasion arise, develop into other kinds of cells. They are, therefore, also known as *indifferent cells.*

The *cnidoblasts* or *stinging cells* (Fig. 105) are small specialized cells embedded in the outer epithelial part of the epithelio-muscular layer. They are particularly abundant in the tentacles

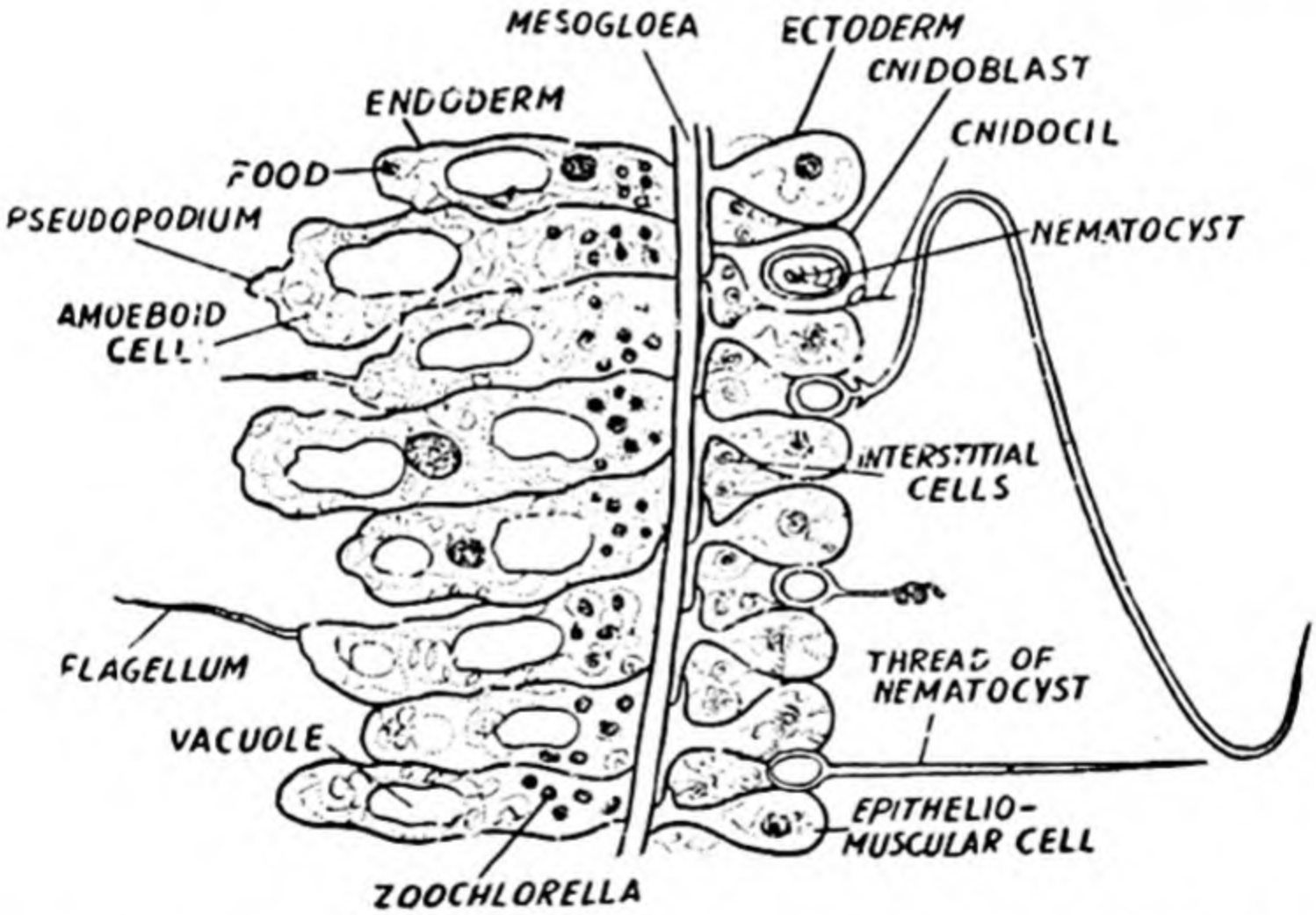


Fig. 104. Part of a transverse section of *Hydra* (highly magnified),

where they occur in groups or *batteries.* They arise from the interstitial cells and migrate to the surface. Each cnidoblast is a pear-shaped cell with a short stiff process, the *cnidocil,* projecting from the narorw end which is directed outwards.

In addition to the nucleus the cnidoblast contains an ovoid sac, the *nematocyst*, containing a fluid, known as *hypnotoxin*. The

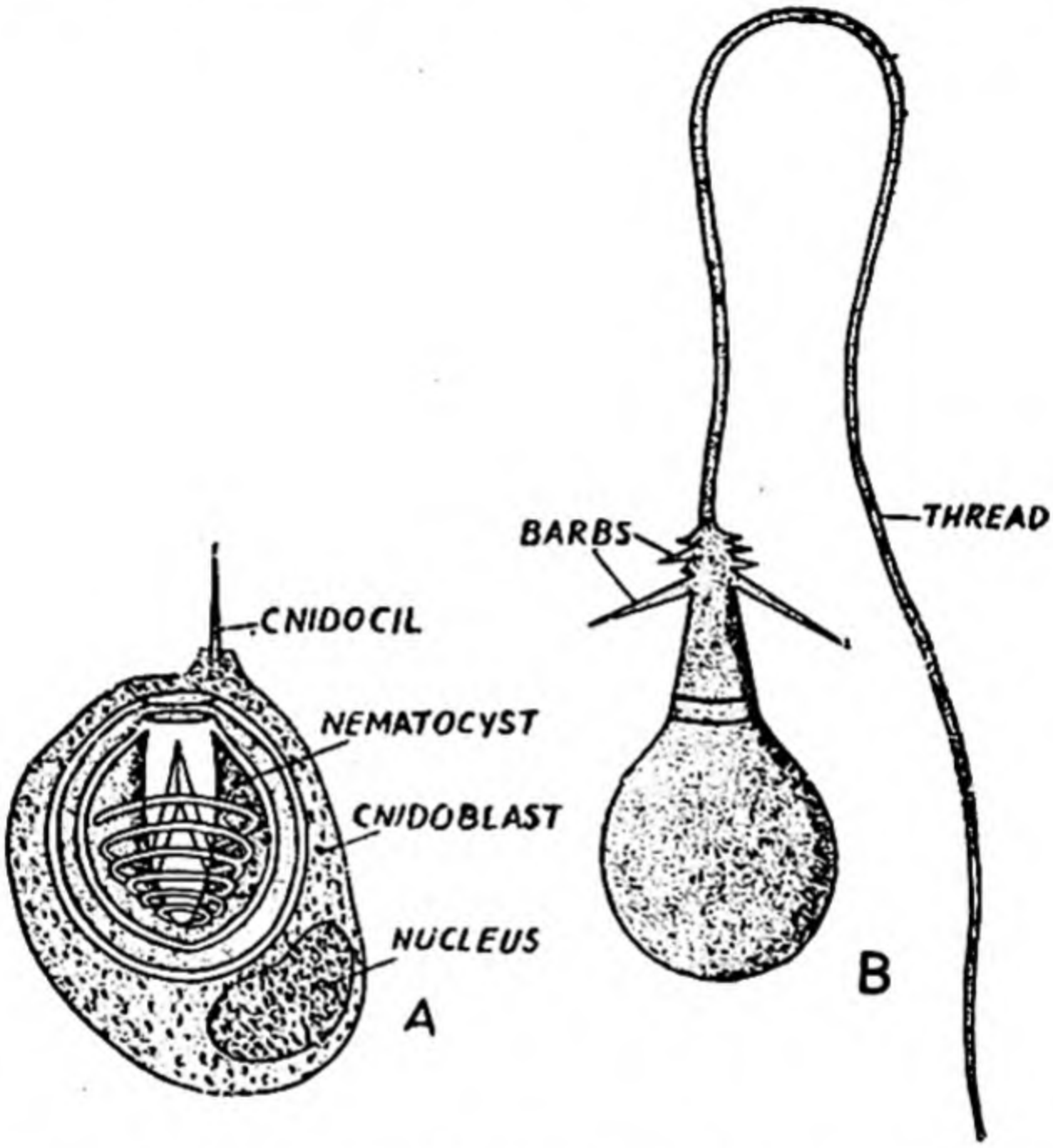


Fig. 105. A, cnidoblast containing an invaginated nematocyst ; B, an evaginated nematocyst. (After Schneider).

sac is prolonged into a long hollow coiled thread. The protoplasm of the cnidoblast surrounding the nematocyst is highly contractile. The cnidocil may be compared to the trigger of a gun. When it is touched the protoplasm in the wall of the cnidoblast is stimulated to contract. This squeezes the sac and causes the thread to be everted or turned inside out. The hypnotoxin has a paralysing effect on small aquatic creatures

which form the food of *Hydra* or may be its potential enemies.

There are three main kinds of nematocysts (Fig. 104). One of them is a large kind which ejects a long straight thread with barbs at the base. It is used for paralysing the prey and may also act as an organ of defence. When it is discharged the barbs first inflict a wound on the prey, then the thread pierces it and finally the hypnotoxin is injected which paralyses the prey. The other two kinds of nematocysts are smaller and without barbs. One of them has a spiral thread which coils round the prey, after it has been paralysed, and the other has a straight sticky thread which adheres to the prey, or other objects. The nematocysts, when once discharged, are lost but are renewed by the interstitial cells.

The ectodermal cells of the foot are glandular and secrete a sticky substance by which the animal fixes itself to a solid object.

The *nerve cells* are small and branched with large nuclei. They are scattered throughout the ectoderm in the region of the interstitial cells. The fine branches of the neighbouring cells anastomose to form a *nerve-net*, enabling stimuli to be conveyed from one part of the body to another. The nerve cells are in contact with the cnidoblasts and muscle fibres.

The *endoderm* (Fig. 104) consists mainly of columnar cells which are larger than those of the ectoderm, and have a nutritive function. Their cytoplasm contains large vacuoles. Their outer ends are produced into muscle-processes which run round the body and not along it, as those of the ectoderm. The two sets of muscles enable the animal to contract or extend its body. The inner ends of the endodermal cells are produced into pseudopodia which may be withdrawn and replaced by flagella. The pseudopodia can ingest food particles as in *Amoeba*. Amongst the ordinary endoderm cells are present glandular cells, which are particularly abundant in the hypostome

and are absent in the tentacles. They secrete a digestive juice which is poured into the enteron.

In *Hydra viridis* the endodermal cells contain unicellular green plants, known as *zoochlorellae*. The green colour of this species is due to their presence. The animal and the plants live together for mutual benefit. The zoochlorellae obtain from *Hydra* carbon dioxide and water, produced as by-products during the animal's respiration, and build up carbohydrates from them by photosynthesis. The carbohydrates become further converted into proteins by combining with nitrogen taken from the nitrogenous waste products of the animal. *Hydra* in return obtains from the zoochlorellae oxygen, given off as a by-product during photosynthesis, and uses it for its respiration. It also obtains carbohydrates and proteins from the zoochlorellae and uses them as food. This type of intimate and mutually beneficial association between two different species is known as *symbiosis*. In *Hydra fusca* the endodermal cells contain yellow unicellular plants known as *zooxanthellae*.

Movements. The movements of *Hydra* are chiefly caused by the muscle-processes of the ectodermal and endodermal cells. As already stated, the muscle-processes of the ectodermal cells run longitudinally and those of the endodermal cells circularly. When the longitudinal muscle-processes contract the animal becomes shorter and thicker, when, on the other hand, the circular muscle-processes contract the animal becomes longer and thinner. *Hydra* can bend its body and tentacles by contraction of one side and elongation of the opposite side. During these movements the body remains fixed to the substratum by the foot. *Hydra* can also move from place to place by *gliding*, *looping* or *somersaulting*. It glides by means of the pseudopodia-like extensions of the cells of the foot. In looping (Fig. 106A) the animal bends on one side to such an extent that its tentacles touch the substratum and adhere to it by means of the nematocysts with sticky threads.

The foot is now drawn towards the tentacles and fastened to the ground near them. The tentacles then release their hold and

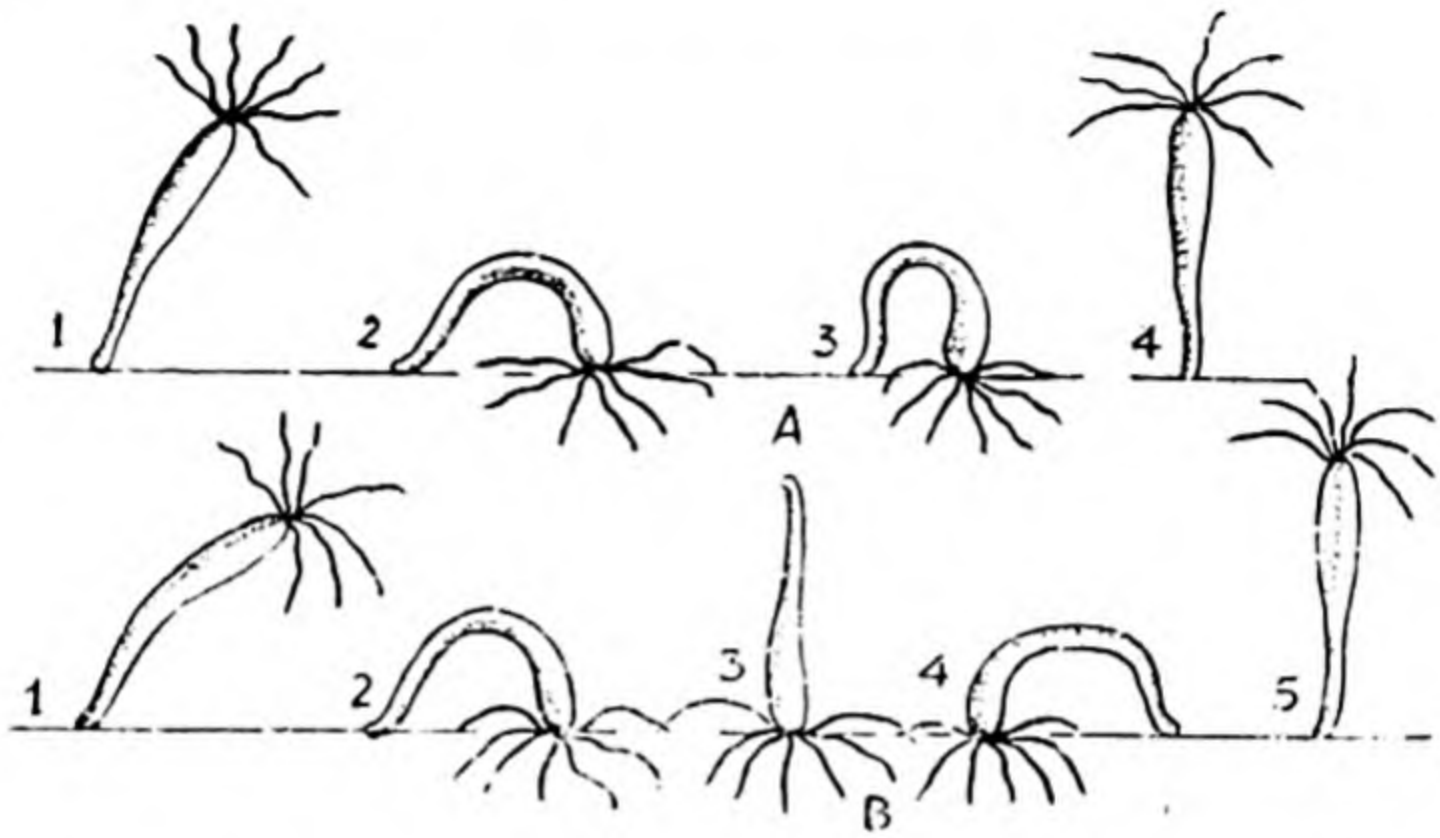


Fig. 106. Two modes of locomotion in *Hydra*. A, looping; B, somersaulting.

the body is straightened. The process is repeated and the animal moves on. In somersaulting (Fig. 106B) *Hydra* bends its body and fixes the tentacles on the ground, as in looping. It then lifts its foot, straightens its body and stands on its tentacles. The body continues its movement till it completes a semicircle and touches the ground with the foot which is then anchored there. The body is then straightened and the polyp assumes the normal upright position. Thus the animal moves forward. Occasionally the foot of *Hydra* secretes a gas bubble, enclosed in mucus, which helps it to rise in the water and float at the surface.

Nutrition, Respiration and Excretion. *Hydra* is carnivorous in its diet. Its food consists of water-fleas, insect larvae, eggs of small fishes, etc. When hungry it attaches itself to a weed or some other object by the foot and extends its

body and tentacles into the water (Fig. 107). By the swaying movements of the body it hunts for its prey. When a small

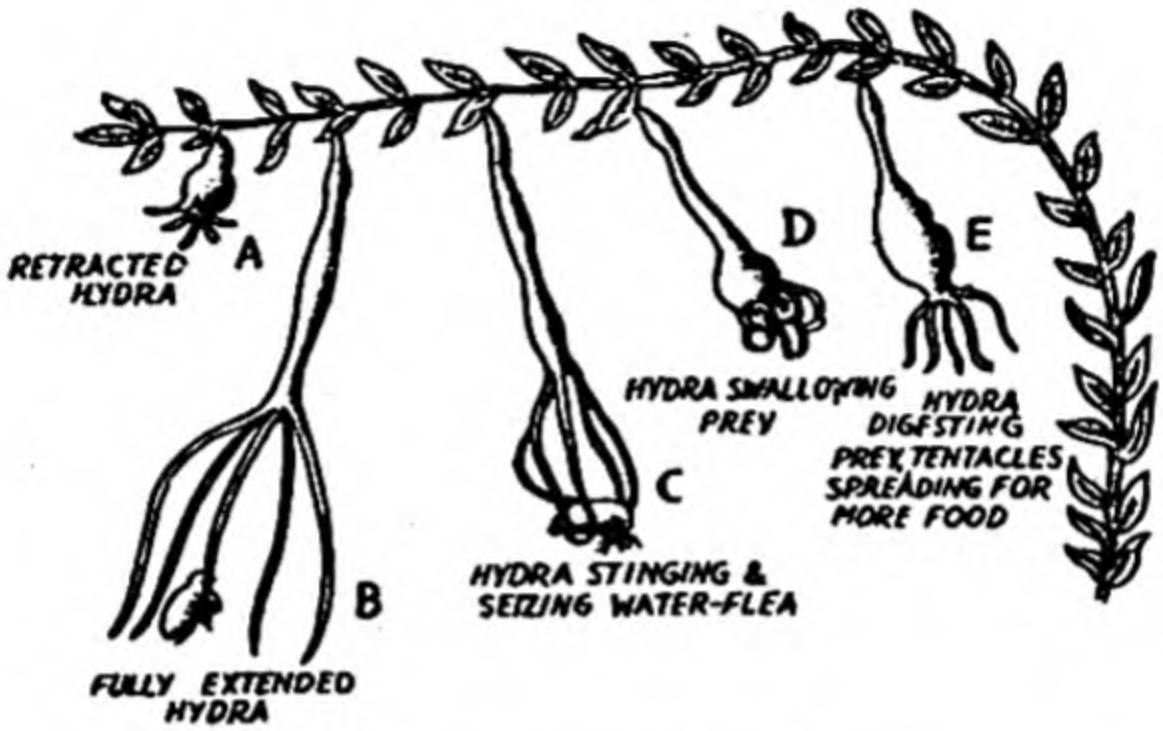


Fig. 107. *Hydra* capturing its prey.

aquatic organism touches a tentacle all the three types of nematocysts are discharged to capture it. The large barbed nematocysts injure and paralyse the prey while the two small types hold it firmly. In the meantime the other tentacles curve round the prey and, by contracting, take it into the mouth which has already begun to open. The prey, thus, enters the enteron. A well-fed hydra does not attempt to catch the prey even when the latter is within easy reach.

As soon as the food goes into the enteron, the gland-cells of the endoderm secrete a disgestive fluid containing enzymes, by the action of which the digestion of food is partly completed in the enteron. The digested food is distributed to all parts of the enteron by the action of the flagella and is finally absorbed by the endodermal cells. This type of digestion is known as *intercellular* and is similar to that found in the frog. A part of the food, however, is engulfed by the endodermal cells by means of their pseudopodia and the digestion takes

place inside the cells as in *Amoeba*. This type of digestion is known as *intracellular*. Digestion in *Hydra*, thus, is both intercellular and intracellular. As there is no anus, the undigested food is egested through the mouth. The products of digestion are conveyed to all parts of the body by diffusion through the cells, there being no blood vascular system.

There are no special organs of *respiration* and *excretion*. Oxygen dissolved in the surrounding water is absorbed by the ectoderm and the endoderm, and the carbon dioxide and waste products are eliminated from the body through the general surface of the two layers.

Reproduction. Reproduction in *Hydra* takes place both *asexually* and *sexually*. The asexual process is known as *budding*. A bud (Fig. 102) arises as a hollow outgrowth of the body-wall. Its cavity is a prolongation of the enteron and its wall consists of ectoderm, mesogloea and endoderm which are continuous with the same layers of the parent. The bud grows in size and a circlet of tentacles is formed at its distal end. A mouth appears in the centre of the tentacles. The young hydra now becomes detached from the parent and begins to lead an independent existence. Buds are generally formed in the middle part of the body. Several buds may be present at the same time, and a bud may bear smaller buds. A colony may, thus, be formed but it is of a temporary nature, as the buds, sooner or later, separate from the parent.

Hydra possesses a high power of *regeneration*, that is, it can replace lost parts of the body. Experiments have shown that not only will *Hydra* replace a lost part, say a tentacle, but if its body is cut into several pieces, each piece will grow into a complete *Hydra*. The pieces, however, should not be too small and must contain portions of both layers. The power to regenerate is gradually lost in the higher animals and is least

developed in the mammals. In main it is reduced to the healing of wounds only.

Sexual reproduction takes place by the fusion of male and female sex-cells produced by the sexual organs or gonads which are of two kinds, *testes* or *spermaries* and *ovaries* (Fig. 102). In most species of *Hydra* the testes and ovaries are present in the same individual. As a rule, *Hydra,* therefore, is *hermaphrodite.* The gonads, however, are not permanent structures but are developed temporarily during the breeding season from the interstitial cells which multiply so rapidly that the ectoderm at the particular spot bulges out. There are generally several testes found on the distal part of the body and a single ovary found on its proximal part.

The interstitial cells constituting the testes become spermatocytes and each undergoes two maturation divisions resulting in the formation of spermatozoa. Each sperm has an ovoid head, a narrow neck and a long slender tail. By the rupturing of the ectoderm, forming the outer wall of each testis, the sperms are set free, and they swim about by the lashing movements of their tails.

In the ovary only one interstitial cell develops into an ovum. It grows at the expense of the outer cells of the ovary by engulfing them by means of pseudopodia. Its cytoplasm becomes packed with yolk granules, and in the case of *Hydra viridis* it contains, in addition, zoochlorellae. It assumes a globular form and is known as an oocyte. It secretes round itself a gelatinous covering. Polar bodies are formed and the oocyte matures into an ovum. The ectodermal wall now ruptures and the ovum protrudes on the surface. It, however, remains attached to the body by means of a stalk. The ovum is fertilized by one of the sperms swimming in the water.

The early development takes place while the egg is still

attached to the body of the parent. Segmentation is *holoblastic* and *equal*, and results in the formation of a solid mass of cells, the *morula*, which is converted into a single-layered hollow ball of cells, the *blastula*, its cavity being known as the *blastocoele*. The two-layered *gastrula* is formed by repeated divisions of the cells of the blastula on its inner side and the daughter cells dropping off into the blastocoele. This process is known as *delamination*, which is continued till practically the whole cavity is filled up. The inner cells constitute the endoderm and the outer cells the ectoderm. In the centre of the endoderm cells a cavity, the *enteron*, makes its appearance. While these changes are taking place a thick spiny covering of a horny substance is secreted by the ectoderm The embryo now drops off from the parent and, protected by the horny covering, lies dormant during the unfavourable period. During the resting stage the embryo may be carried to distant places by water currents or in mud sticking to the feet of birds. This effects the dispersal of the species. On the return of favourable conditions the horny envelope spilts and the embryo becomes free. The mouth and tentacles are formed at one end of the body, and the young *Hydra* feeds and grows to become the adult.

OBELIA

We have just learnt that *Hydra* reproduees itself by budding. In this process buds are produced which, after some time, become detached to lead an independent existence. If, however, the buds were to remain permanently attached to the body of the parent a colony of individuals would be formed. This actually occurs in many animals related to *Hydra*. They are known as *hydroids* and the individuals in a hydroid colony are called *zooids*. Most of the hydroids are found in the sea. A common example is *Obelia geniculata*.

Obelia (Fig. 108) is generally found as a whitish fur-like growth on sea-weeds, stones or wooden piers It consists of a horizontal portion, the *hydrorhiza* by which the hydroid is attached to the substratum and an upright stem, the *hydrocaulus* which gives off lateral branches in an alternate manner, each branch terminating in a zooid. When examined under the low power of the microscope the colony is found to consist of two distinct layers, an outer *perisarc* and an inner *coenosarc*. The latter is the living part of the animal and, like the body-wall of *Hydra*, consists of an outer *ectoderm*, an inner *endoderm* and an intermediate *mesogloea*. It encloses a cavity which corresponds to th enteron of *Hydra* and which is continuous throughout the colony. The perisarc is a transparent horny layer secreted by the ectoderm.

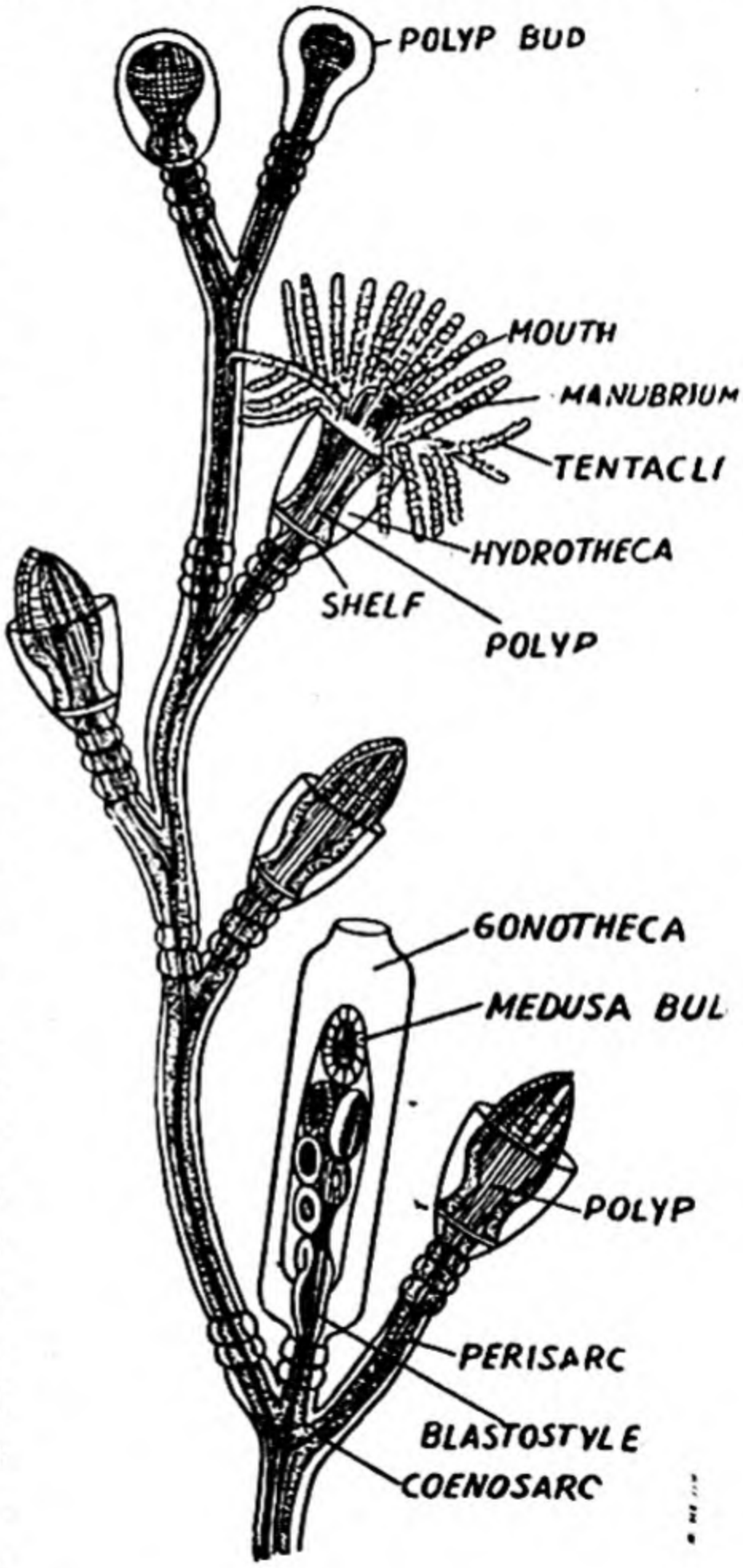


Fig. 108. A portion of *Obelia* colony.

It protects the soft parts and makes the stems rigid so that they may bear the weight of the colony. The perisarc and

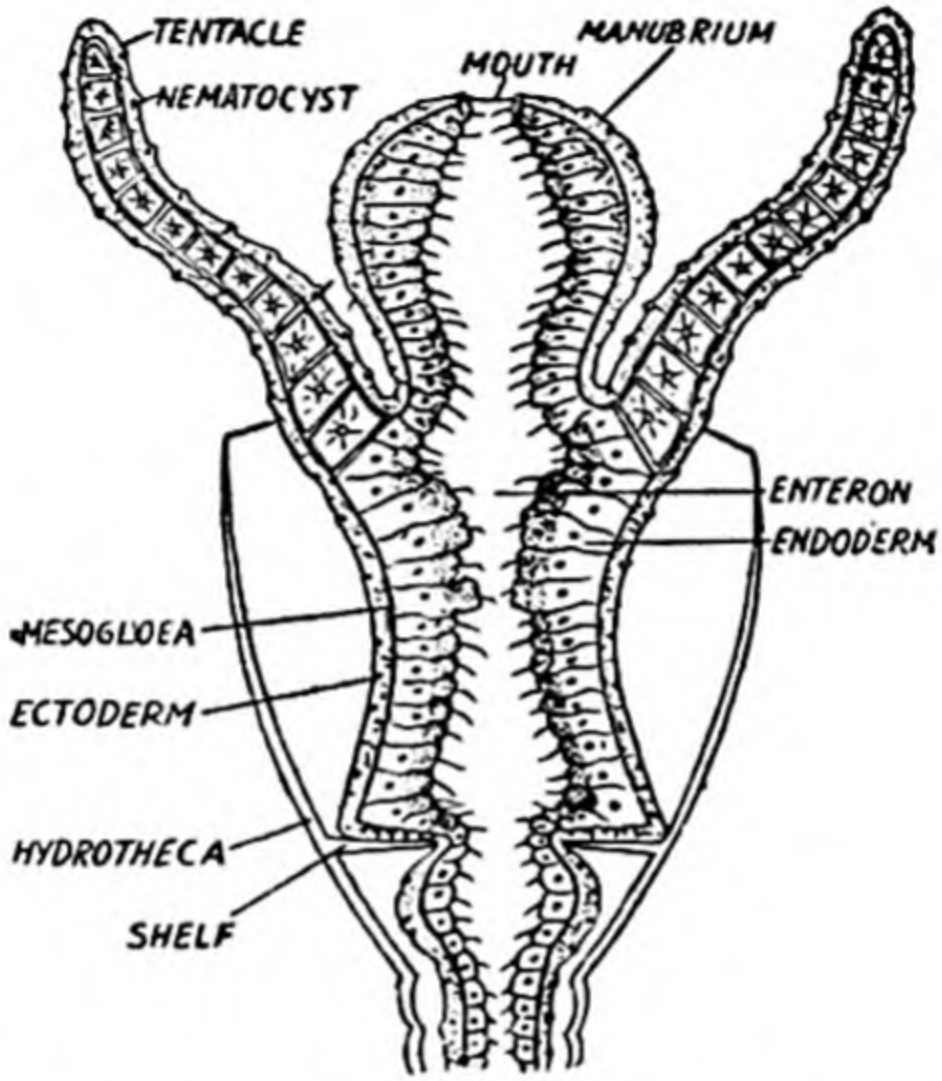


Fig. 109. Vertical section of a polyp of *Obelia* (highly magnified).

the coenosarc are at first in contact with each other but, as growth proceeds, the two layers move apart leaving a space between them except at certain places where they remain united. A colony of *Obelia* bears three kinds of zooids, namely, the *polyps*, *blastostyles* and *medusa-buds*. The occurrence of more than two types of individuals in a single species, as in *Obelia*, is known as *polymorphism*.

Structure of a Polyp. The majority of the zooids are of the polyp type. Each *polyp* or *hydranth* (Fig. 109) is like a miniature *Hydra*, enclosed in a transparent, cup-shaped investment, the *hydrotheca*, which is an extension of the perisarc

of the branch bearing the zooid. The hydrotheca, near its base, is produced inwards into a circular *shelf* which has an opening in the centre. The polyp rests on the shelf and is continuous with the coenosarc of the colony through the central opening. The polyp is produced, at the distal end, into a conical projection, the *manubrium* or *hypostome*, which bears the mouth at its tip. There are about two dozen tentacles arranged in a circle round the base of the manubrium. The mouth leads into the enteron which is continuous with the cavity of the colony. The body of the polyp consists of the same layers as in *Hydra*. There is an outer *ectoderm*, an inner *endoderm* and an intermediate non-cellular *mesogloea*. The tentacles, however, are solid having a core of endoderm cells.

Structure of a Madusa. The medusae originate as small buds from special zooids, known as *blastostyles*, which are generally found towards the base of the colony in the axils of zooids. The blastostyle has no mouth or tentacles. It is enclosed in a cylindrical capsule, the *gonotheca*, which corresponds to the hydrotheca of the polyp. The *medusa buds*, when mature, are saucer-shaped bodies, each attached to the blastostyle by its convex surface. Ultimately they escape as tiny medusae through an aperture in the gonotheca and start an independent and active life.

The full-grown medusa (Figs. 110 and 111) has the shape of an umbrella. Its convex surface is known as the *ex-umbrella* and the concave surface as the *sub-umbrella*. From the centre of the sub-umbrella, projects downwards a hollow process, the *manubrium*, which bears at its free end a four-sided aperture, the *mouth*. The edge of the umbrella is produced inwards into a narrow projection, the *velum*, and bears *tentacles* which are sixteen in the young medusa but increase in number as the medusa grows older. At the bases of eight of the tentacles,

two in each quadrant, there are minute vesicles, the *lithocysts*, each containing a calcareous particle, the *lithite*. The litho-

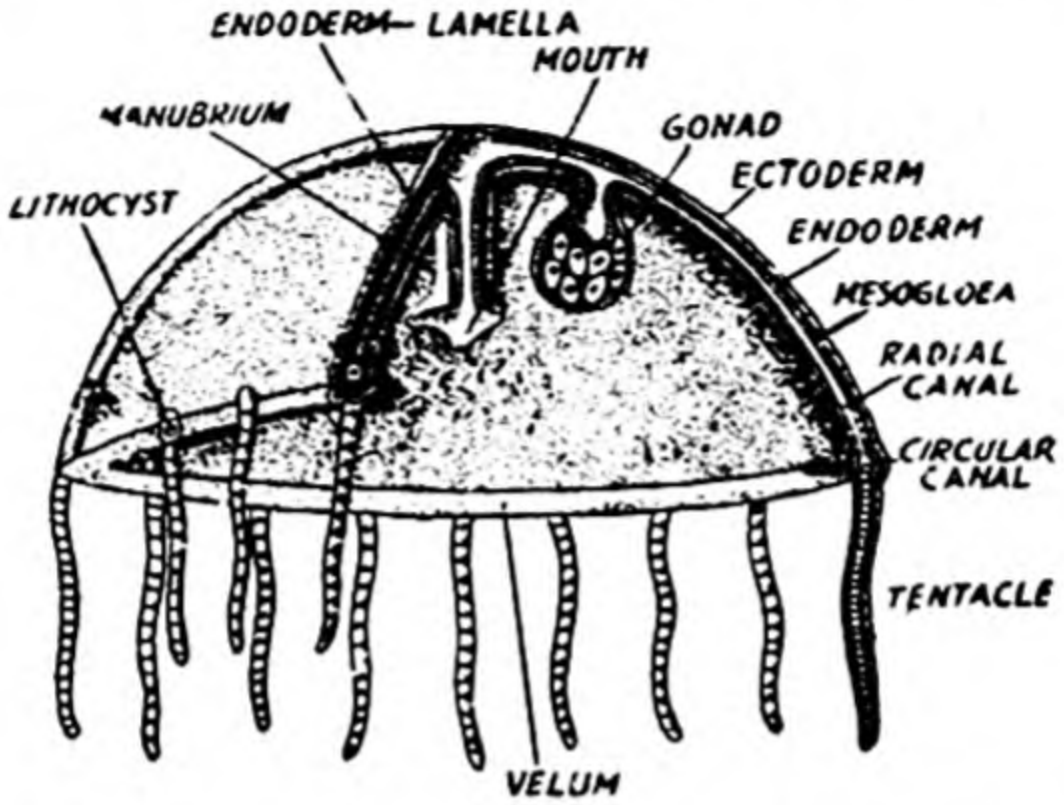


Fig. 110. Medusa of *Obelia* with a part of the umbrella removed (diagrammatic).

cysts are the organs of the sense of direction and equilibrium. They have, therefore, been also named *statocysts*.

The mouth opens into the cavity of the manubrium which is continued into four *radial canals*, runing through the substance of the umbrella at equal distances from one another. The four radial canals open into a *circular canal* which runs round the margin of the umbrella. To the inner side of the circular canal, running round the base of the velum, is a double *nerve-ring*, which represents a rudimentary nervous system. There are four *gonads* on the sub-umbrella, each in connection with a radial canal.

The exposed parts of the body of the medusa, namely, the manubrium, sub-umbrella, gonads, velum, tentacles and ex-umbrella are covered with a continuous layer of ectodermal cells. The cavity of the manubrium, the radial canals and

the circular canal are lined by endoderm, which extends as a thin sheet, the *endoderm lamella*, between the radial canals in

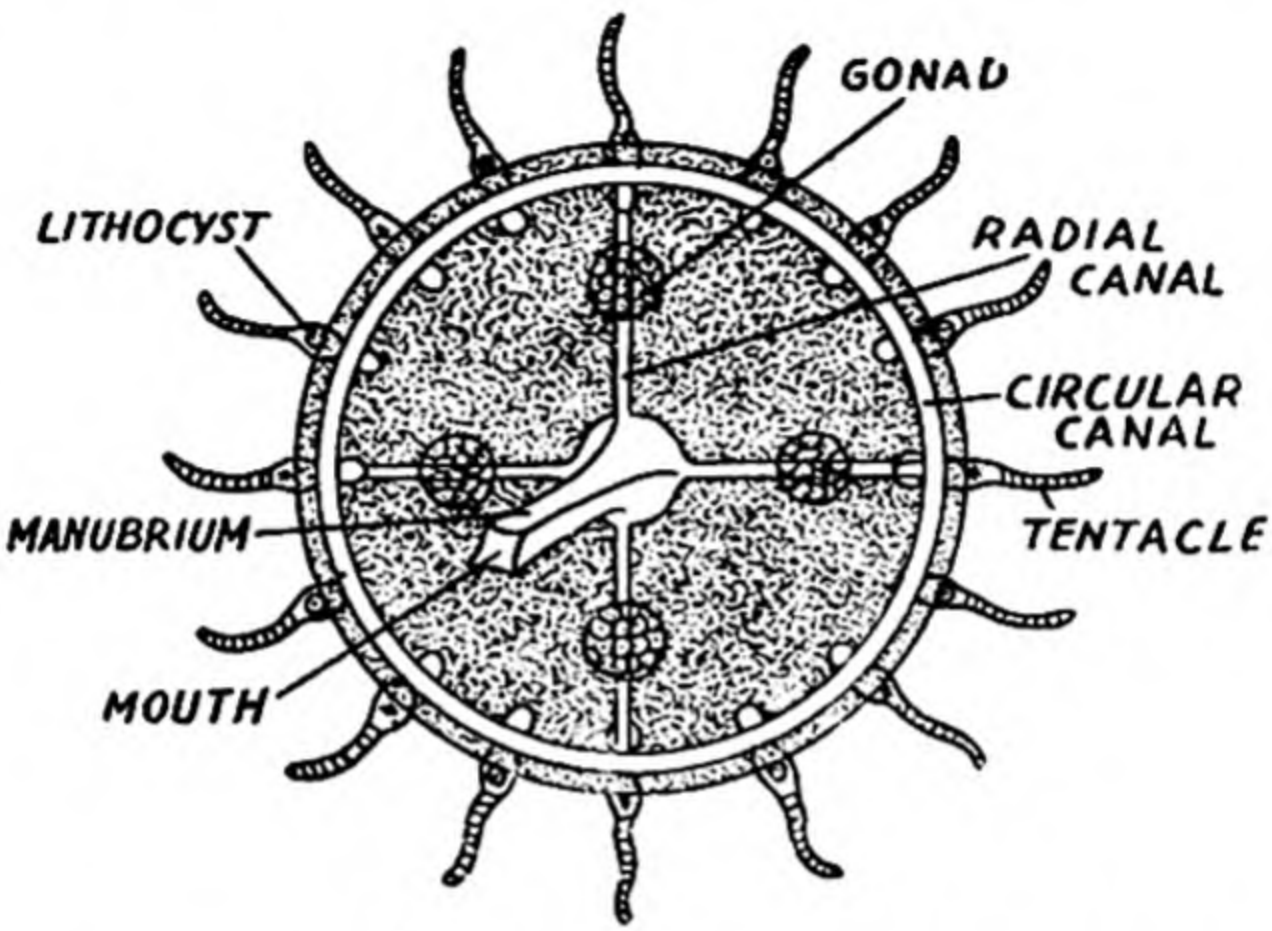


Fig. 111. Medusa of *Obelia* seen from the ventral side.

the substance of the umbrella. The tentacles, which are solid, have a core of endodermal cells. Between the ectoderm and endoderm, everywhere, there is a non-cellular mesogloea. The endoderm does not extend into the velum which consists of a double layer of ectoderm with mesogloea in the middle. The nerve-ring, lithocysts and gonads are ectodermal in origin. The ectoderm of the tentacles, as in *Hydra*, contains numerous nematocysts.

The medusa floats in the sea, with the manubrium and the tentacles hanging downwards. It swims by rhythmical contractions of the sub-umbrella which force out the water through the opening of the umbrella and make the organism move with jerks in the opposite direction. The velum plays an

important role in swimming. It offers resistance to the outgoing water thus increasing its pressure in the centre.

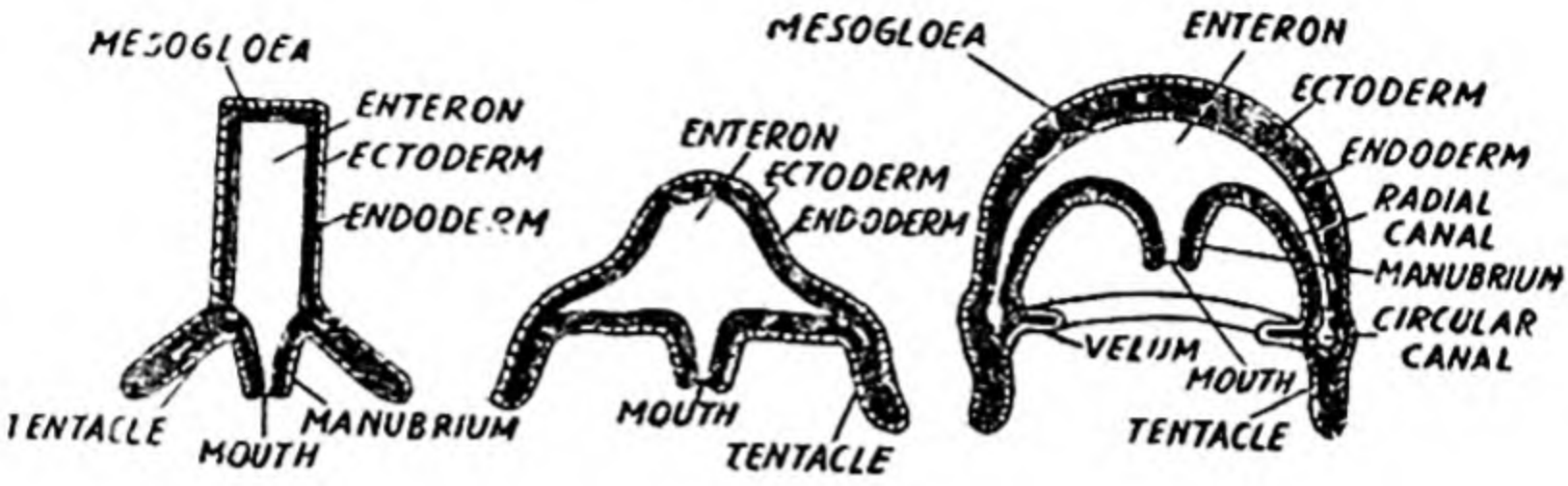


Fig. 112. Derivation of the medusa from the polyp.

Comparison of Polyp and Medusa. Although the polyp and the medusa appear so different from each other, they are both built on the same general plan, and one can be easily derived from the other (Fig. 112). The resemblance between the two becomes evident if the polyp is turned upside down so that its manubrium and the tentacles, like those of the medusa, hang downwards. Now if the polyp, in the region of the tentacles, is pulled out and the manubrium pushed up an umbrella-like medusoid form is easily derived. This change in the shape of the polyp brings its walls together, thus obliterating the spacious enteron, except along the radial and circular canals. The endoderm lamella between the canals in the substance of the umbrella marks the region where the walls have coalesced.

Reproduction. As mentioned above, there are four gonads in the full-grown medusa hanging from the sub-umbrellar surface in immediate relation with the radial canals. Each gonad (Fig. 110) is an ovoid sac. Its outer wall consists of a layer of ectodermal cells, continuous with the ectoderm covering the sub-umbrella, while its inner wall is a prolongation of the

endodermal lining of the radial canal. It encloses a short extension of the cavity of the radial canal. The gonad contains

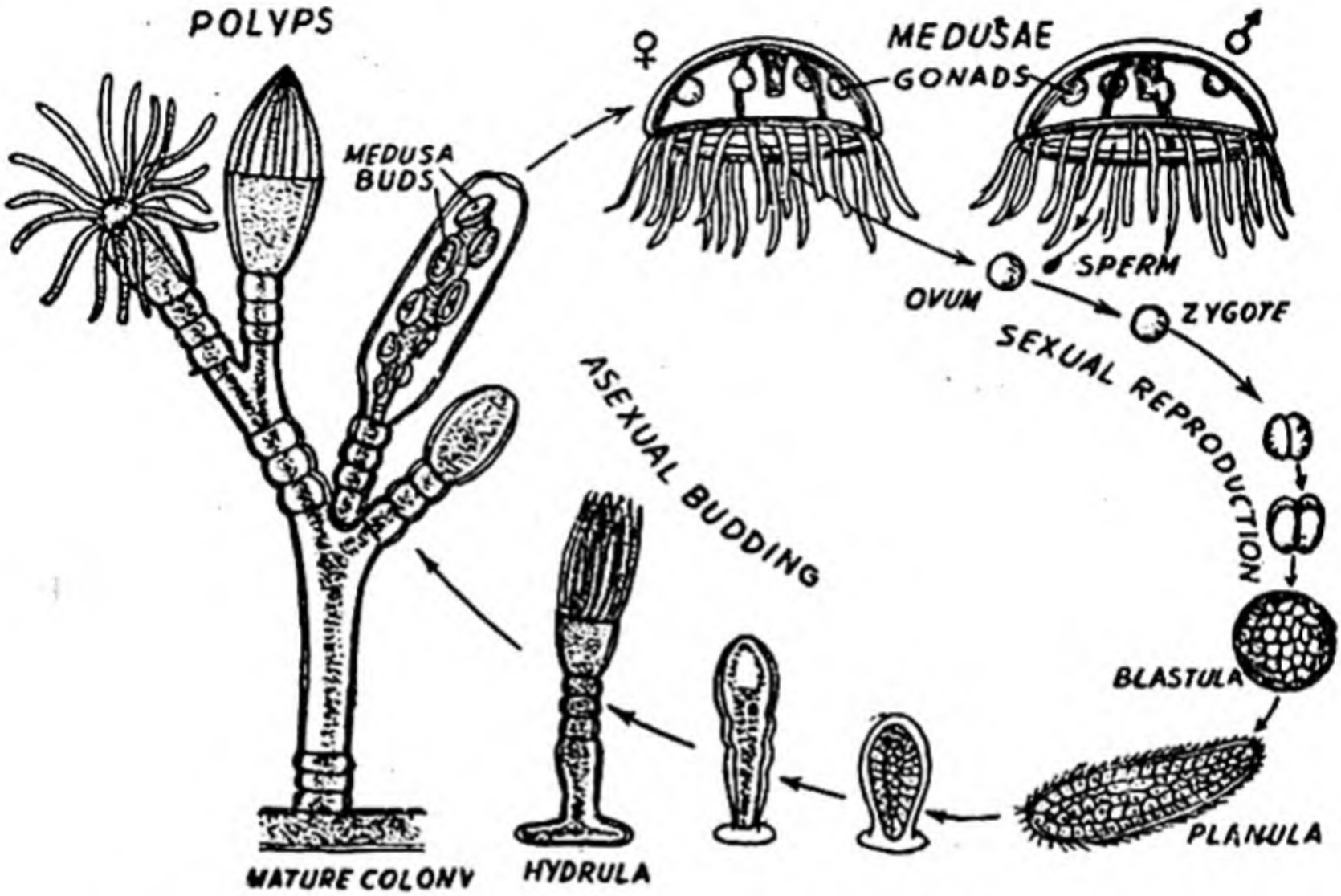


Fig. 113. Development and life-history of *Obelia*. (Modified from Wolcott).

sex-cells which may be either ova or sperms. The medusa therefore, is unisexual. The sex-cells are ectodermal in origin. By the rupture of the ectodermal wall of the gonad they are shed into the surrounding water where fertilization takes place.

The fertilized ovum develops first into a morula, then into a blastula and finally into a gastrula. The gastrula consists of an outer ciliated layer of ectodermal cells and an inner mass of endodermal cells, enclosing a cavity, the rudiment of the enteron. By means of the cilia the elongated gastrula swims freely in the water and is now known as a *planula*. After a

short period of free existence the planula fixes itself by one end to a submerged rock or sea-weed. The manubrium, with a mouth, and tentacles appear at the opposite end. The planula is, thus, converted into a simple polyp known as a *hydrula*. By a process of extensive budding the hydrula is gradually converted into the ordinary *Obelia* colony (Fig. 113).

Alternation of Generations. From the account given above it is clear that reproduction in *Obelia* takes place both by asexual and sexual methods. The *Obelia* colony reproduces itself asexually by a process of budding. The medusae bear gonads and give rise to a new *Obelia* colony by a sexual process, that is, by the fertilization of an ovum by a sperm. We, thus, see that in the life-history of *Obelia* the asexual generation (*Obelia* colony) and the sexual generation (medusa) alternate with each other. This phenomenon is known as *alternation of generations* or *metagenesis*.

The presence of two alternating generations in *Obelia* ensures a proper dispersal of the species. As *Obelia* colony is a fixed form, its offspring, unless carried away by some agency, would become crowded at one place where oxygen and food would gradually become insufficient for their needs. The medusae, being active organisms, overcome this difficulty by swimming away from the parent, carrying with them the requisite material (ova and sperms) to establish new colonies, at some distance from their place of birth, where living conditions are more favourable.

Morphological and Physiological Differentiation. We know that every living organism performs certain fundamental activities which include respiration, excretion, response to stimuli, reproduction, etc. In the unicellular forms or the Protozoa, such as *Amoeba* and *Paramecium*, these life activities are performed in a simple way by the single cell of which the body of the animal is composed. In the lowly evolved multi-

cellular forms or Metazoa, like *Obelia*, the different parts of the body have become somewhat differentiated to perform different functions in a little more progressive way than in the Protozoa. In the medusa of *Obelia*, which is more highly organized than the polyp, we find the beginnings of the muscular, nervous and reproductive systems. As we go higher and higher through the Metazoan series there is greater and greater morphological or structural as well as physiological or functional differentiation. In other words the efficiency with which an animal performs its functions depends on the degree of differentiation in its structure.

CHAPTER XXII

THE EARTHWORM

Habitat and Habits. The earthworm, as the name implies, is found in moist earth burrowing up to a depth of twelve to eighteen inches from the surface. As we shall learn later, the earthworm respires through its skin which, therefore, must be kept moist. In dry weather the worm goes deeper into the soil while during heavy rains it comes to the surface of the ground where it finds enough moisture for its needs. The earthworm feeds on earth, which is rich in decaying organic matter. The undigested part is passed out in the form of small pellets or *castings* which are commonly found, in small heaps, in fields and gardens, especially during the rainy season. In this manner a large quantity of earth from the subsoil is brought to the surface in a finely divided form. As it is mixed with the faeces of the worms, it serves as a rich organic manure. The earthworms are, therefore, very useful to the agriculturist as they are constantly ploughing and manuring his land. Darwin, who made observations on the habits of earthworms for forty years estimated that these worms brought to the surface a layer of earth one-fifth of an inch deep during the course of one year.

There are various species of earthworms but *Pheretima posthuma*, being common throughout India, is a convenient type for study. It can be easily distinguished from the two other common species, *P. hawayana* and *P. heterochaeta*, by the presence of the genital papillae on the seventeenth and the nineteenth segments, in line with the male genital pores on the eighteenth segment. In the two latter species the genital

papillae are either absent or are present in groups on the eighteenth and the neighbouring segments.

External Characters. The body of the earthworm (Fig. 114) is long and cylindrical, being well adapted for a burrowing mode of life. A full-grown specimen of *Pheretima posthuma* is about 150 mm. in length and 3-5 mm. in diameter. The anterior end is more pointed than the posterior. The colour of the body is deep brown, the ventral surface being paler than the dorsal, which is marked by a dark median line running throughout the length of the body. This line is due to a narrow strip of muscle applied to the inner surface of the skin and is not the dorsal blood-vessel as is generally supposed. The entire surface of the body is divided, by ring-like grooves or *annuli*, into about 100 to 120 *segments* or *metameres*. As we shall learn later, this external segmentation corresponds to an internal segmentation of the body. This condition of being divided into a number of similar segments is known as *metameric segmentation*.

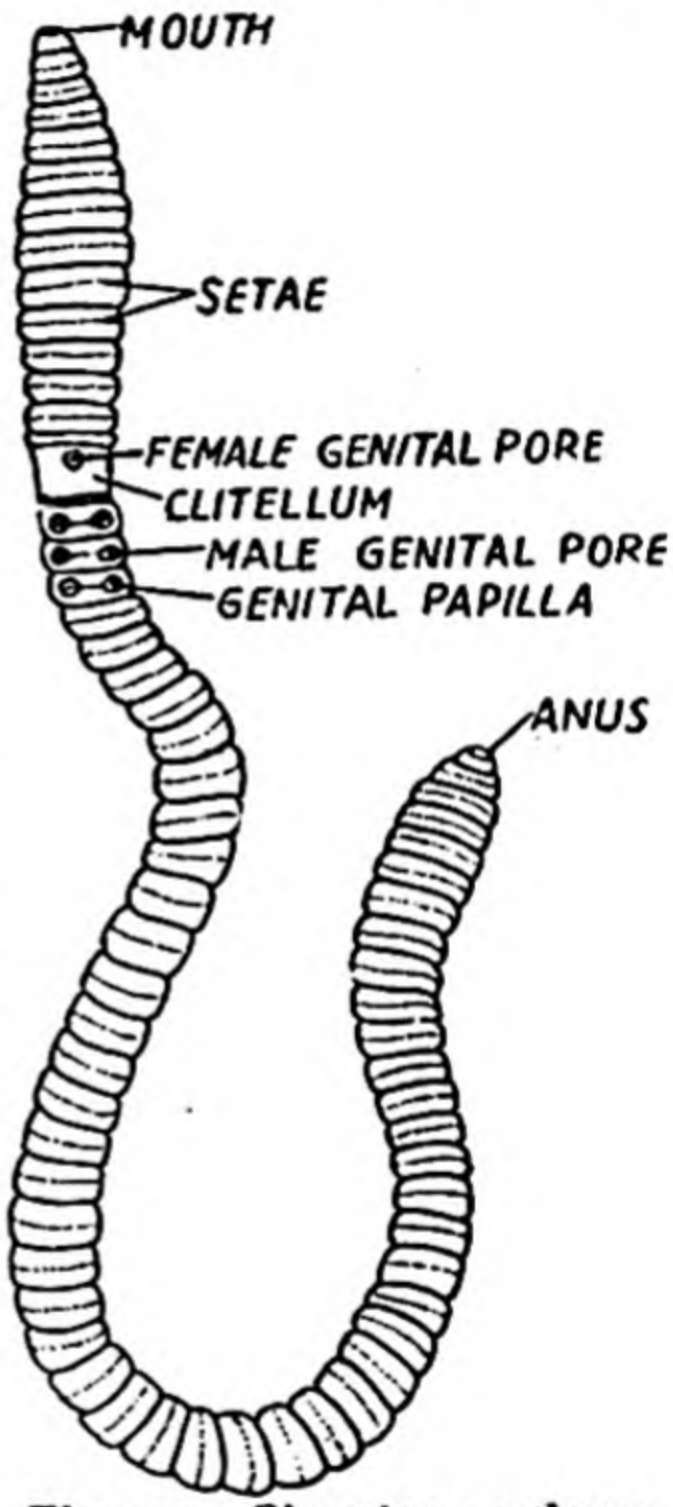


Fig. 114. *Pheretima posthuma*, ventral view. (After Bahl).

A small lip-like projection, the *prostomium*, overhangs the mouth at the anterior end of the body. The first segment, which bears the mouth, is known as the *peristomium*. The prostomium is considered as an extension of the peristomium

and not a distinct segment. In full-grown worms a prominent band of glandular tissue, the *clitellum*, encircles the body

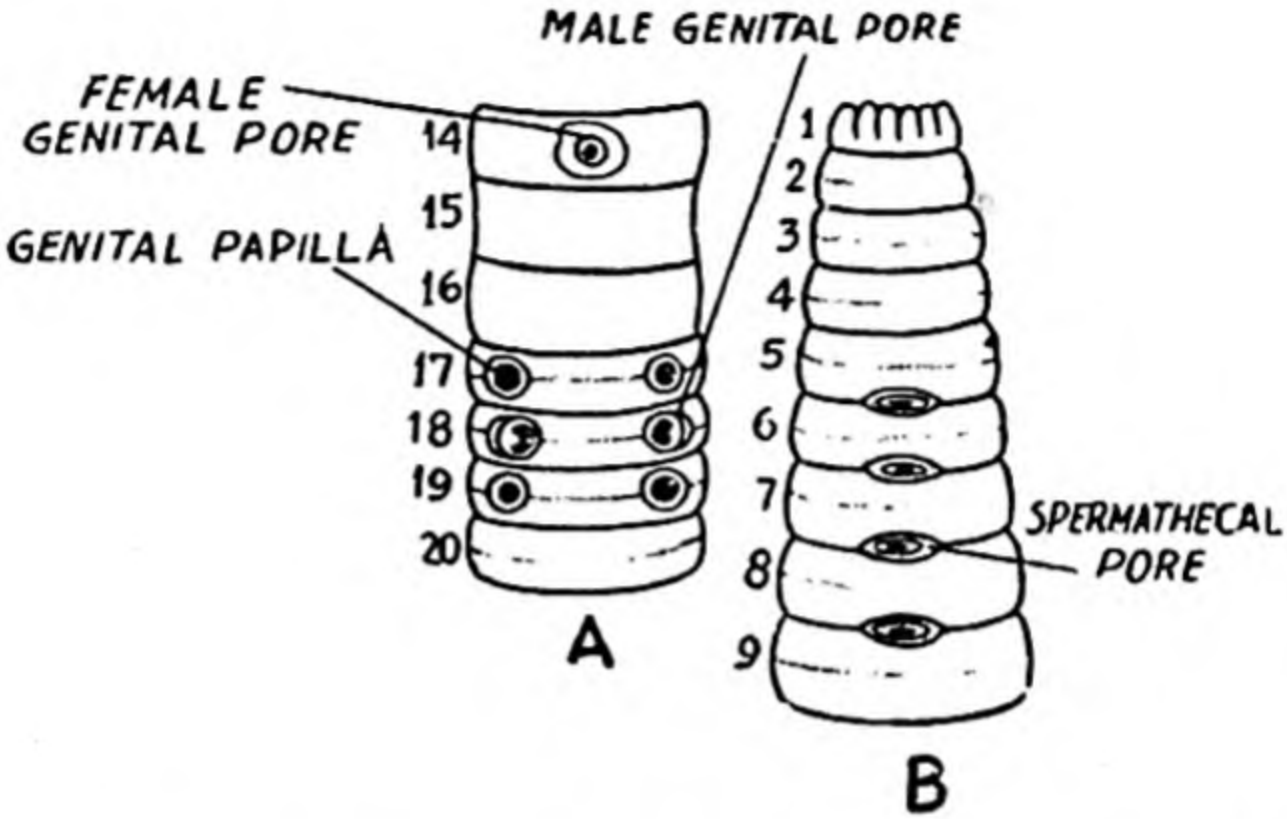


Fig. 115. *Pheretima posthuma.* A, the genital area ; B, a lateral view of the anterior nine segments. (After Bahl).

towards the anterior end. It extends over three segments, namely, the fourteenth, fifteenth and sixteenth. On the ventral surface of the clitellum on the fourteenth segment, that is, the first clitellar segment, is the single median *female genital pore* (Fig. 115 A). Behind the clitellum, on the ventral surface, are three pairs of papillae on three consecutive segments, those on the eighteenth segment bear the *male genital pores* while those on the seventeenth and nineteenth segments are known as *genital papillae*. The latter do not bear any apertures but each has a cup-shaped depression which is liable to be mistaken for a true aperture. There are, in addition to the apertures mentioned above, four pairs of *spermathecal pores* (Fig. 115 B) situated laterally in the grooves between the fifth and sixth, sixth and seventh, seventh and eighth, and eighth and ninth segments. Encircling the middle of each segment, except the

first and the last, is a ring of *f*-shaped chitinous bristles, known as *setae* or *chaetae*, which act as the chief organs of locomotion. In the adult worm the clitellum is devoid of setae which, however, are present in the young individuals in three distinct rows. A series of minute pores, the *dorsal pores*, is found in the grooves between the segments. The first pore lies in the groove between the twelfth and thirteenth segments and there is a pore in each succeeding groove except the last. Through the dorsal pores the body-cavity communicates with the outside. The anus is situated at the posterior end of the body in the last or *anal segment*. The minute openings of the excretory organs or *nephridia*, known as the *nephridiopores*, are scattered all over the surface of the body behind the first two segments. They are difficult to locate in the entire specimen but can be seen in thin sections examined under the microscope.

Body-wall. The body-wall (Fig. 116) consists of a number of layers. The outermost covering is the cuticle which is a non-cellular chitinous membrane. Beneath the cuticle is the epidermis which consists of two kinds of cells : glandular cells which secrete mucus to keep the skin moist and columnar cells which are placed in between the glandular cells. The next layer is the muscular layer which is composed of circular muscles on the outside and longitudinal muscles on the inside. The latter are much thicker than the former. The innermost layer of the body-wall surrounding the coelomic cavity is the parietal layer of the coelomic epithelium, which is extremely thin.

Locomotion. As already mentioned, the chief organs of locomotion in the earthworm are the setae, which are embedded in the body-wall making a ring round the middle of each segment. A seta (Fig. 117) is secreted by a *formative cell*, and is lodged in an epidermal sac, the *setal sac*. It can be protruded or retracted by means of the protractor and retractor muscles

attached to the base of the sac. During locomotion, the anterior part of the body is extended and fixed to the soil by means of

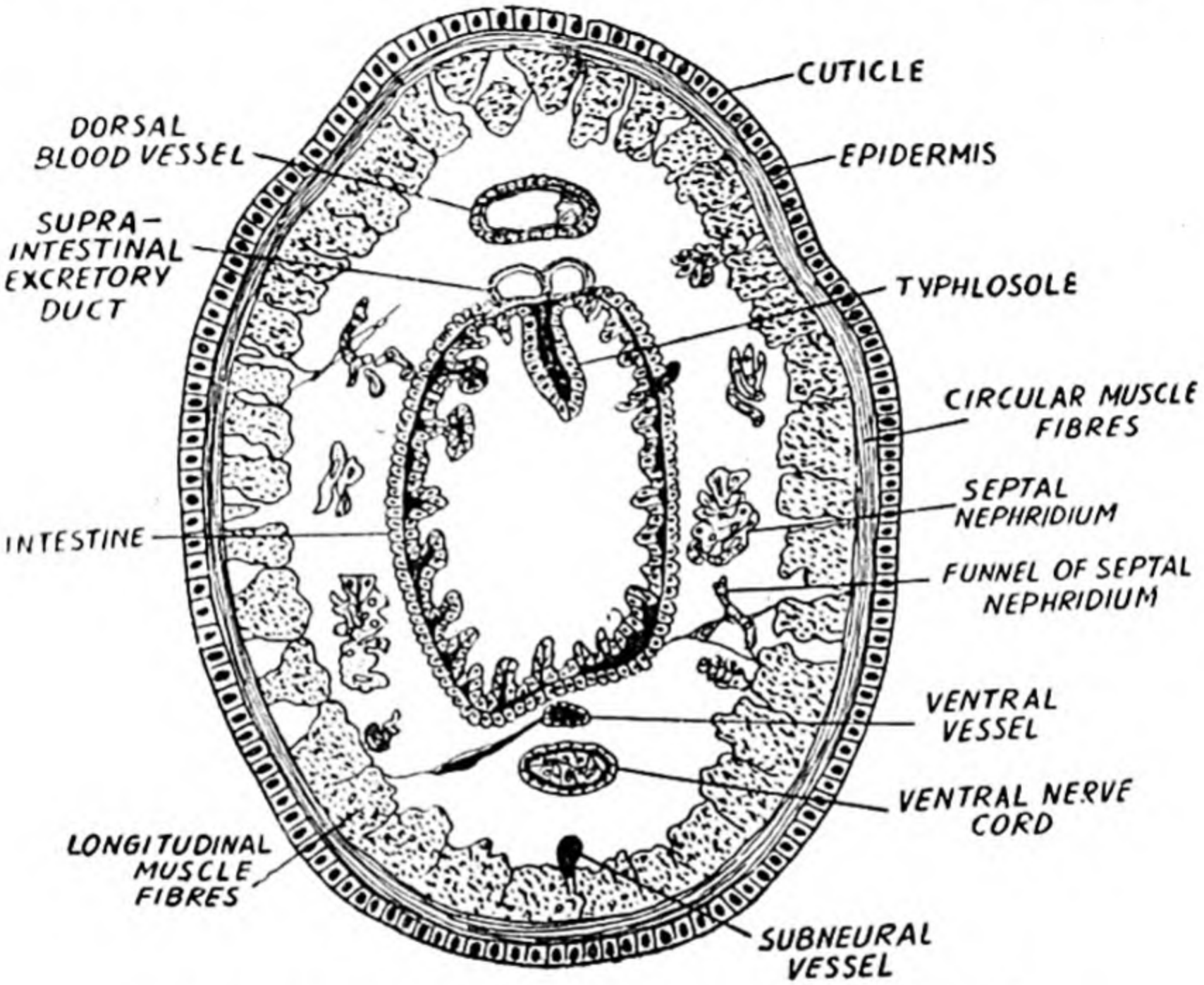


Fig. 116. A transverse secion of the earthworm through the region of the intestine. (After Bahl).

the setae and then the posterior part is drawn up. By repeating this process the worm slowly crawls along. In the act of burrowing the setae assist the animal to get a firm grip of the soil.

Coelom. The alimentary canal of the earthworm is a straight tube running from the mouth to the anus. The space between the alimentary canal and the body-wall is the *body-cavity* or *coelom.* It is, however, not a continuous cavity, as in

the frog, but is broken up into a series of compartments by vertical partitions or *septa* which connect the alimentary canal

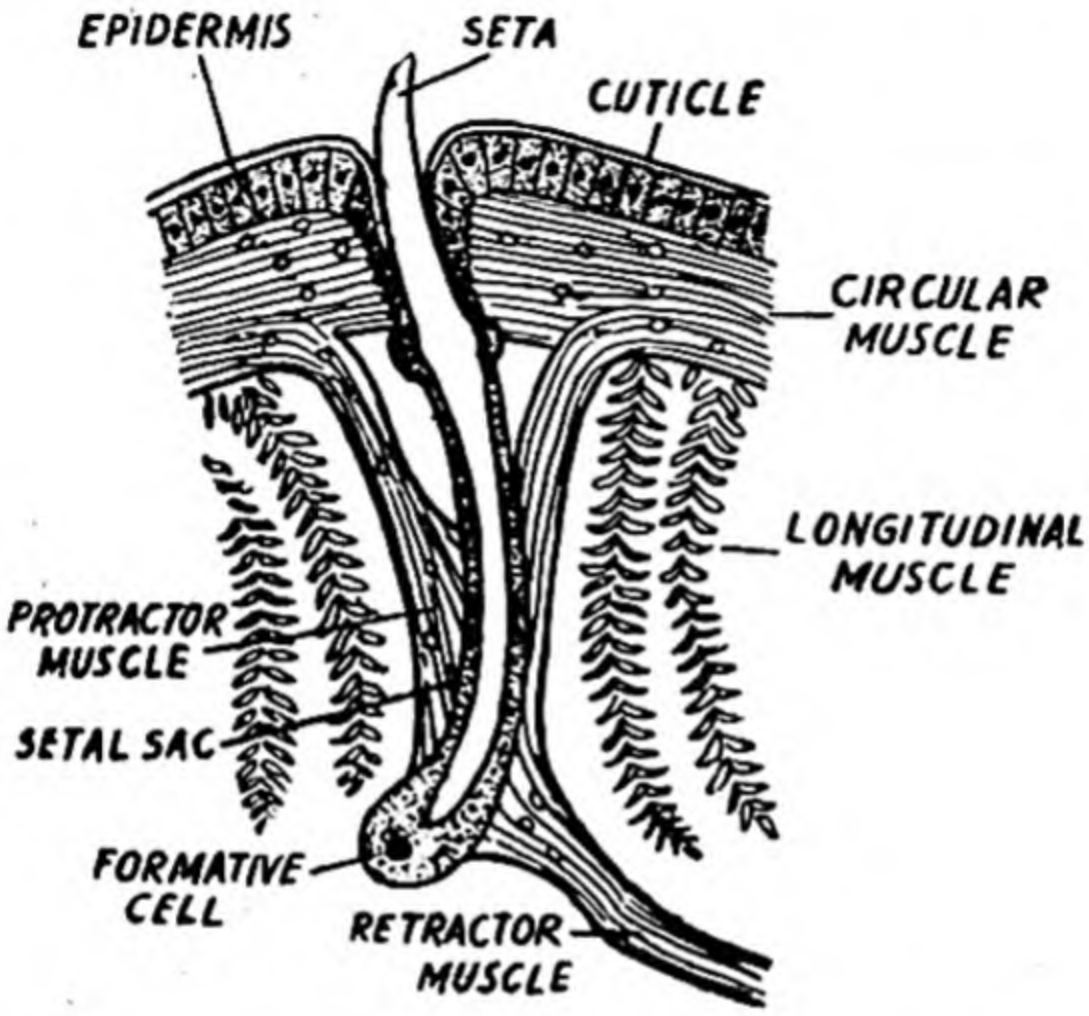


Fig. 117. Part of a transverse section through the body-wall of an earthworm. (After Wheeler).

with the body-wall along the inter-segmental grooves. Each septum consists of a middle layer of connective tissue and muscle fibres covered on both sides by coelomic epithelium. There is a circular aperture in each septum on the ventral border surrounding the nerve-cord. Through these apertures the coelomic compartments communicate with one another. As already mentioned, the coelom communicates with the outside by the dorsal pores. The septa of the first four segments are absent so that the coelom in this region is a continuous space. A number of muscular strands, however, run from the wall of the buccal cavity and the pharynx to the body-wall. The first septum, which is thin and membranous, lies between

the fourth and the fifth segments. The next five septa (Fig. 118) are thick and muscular. One of these, either between the eighth and ninth or between the ninth and tenth segments, is almost invariably absent. The six anterior septa are not vertical but oblique forming six cones, one within the other, with their apices pointing backwards. Behind the eleventh segment the septa are thin and membranous. They lie vertically and separate successive compartments from one another.

The coelom is filled with a milky fluid, the *coelomic fluid*. The function of the coelomic fluid is to kill harmful bacteria and to assist in excretion and respiration. It contains three kinds of cells, namely, (1) large *amoeboid cells* or phagocytes which ingest harmful bacteria by means of their pseudopodia, (2) small *yellow cells* and (3) *circular cells* with characteristic markings on the surface. The coelomic fluid is ejected through the dorsal pores and destroys harmful bacteria which ordinarily would grow on its body.

Two rows of small whitish bodies, known as the *lymph glands* (Fig. 118), lie on the intestine, one on either side of the dorsal blood vessel. The first pair of lymph glands is situated in the twenty-sixth segment and there is a pair in each succeeding segment.

Digestive System. As already mentioned, the alimentary canal (Fig. 118) is a straight tube running from the mouth to the anus. The *mouth* lends into the *buccal cavtiy* which extends from the first to the middle of the third segment. The buccal cavity is protruded and retracted during locomotion by the action of muscles which pass forward and backward from its outer wall to the body-wall. The buccal cavity opens into the pear-shaped *pharynx* from which it is separated by a dorsal groove which lodges the cerebral ganglia. On the dorsal surface of the pharynx lies a glandular body, the *pharyngeal mass* or *bulb*, which consists of musculo-vascular tissue containing deeply staining glandular cells. It is a digestive gland and

through channels in its substance the salivary secretion is poured into the pharynx.

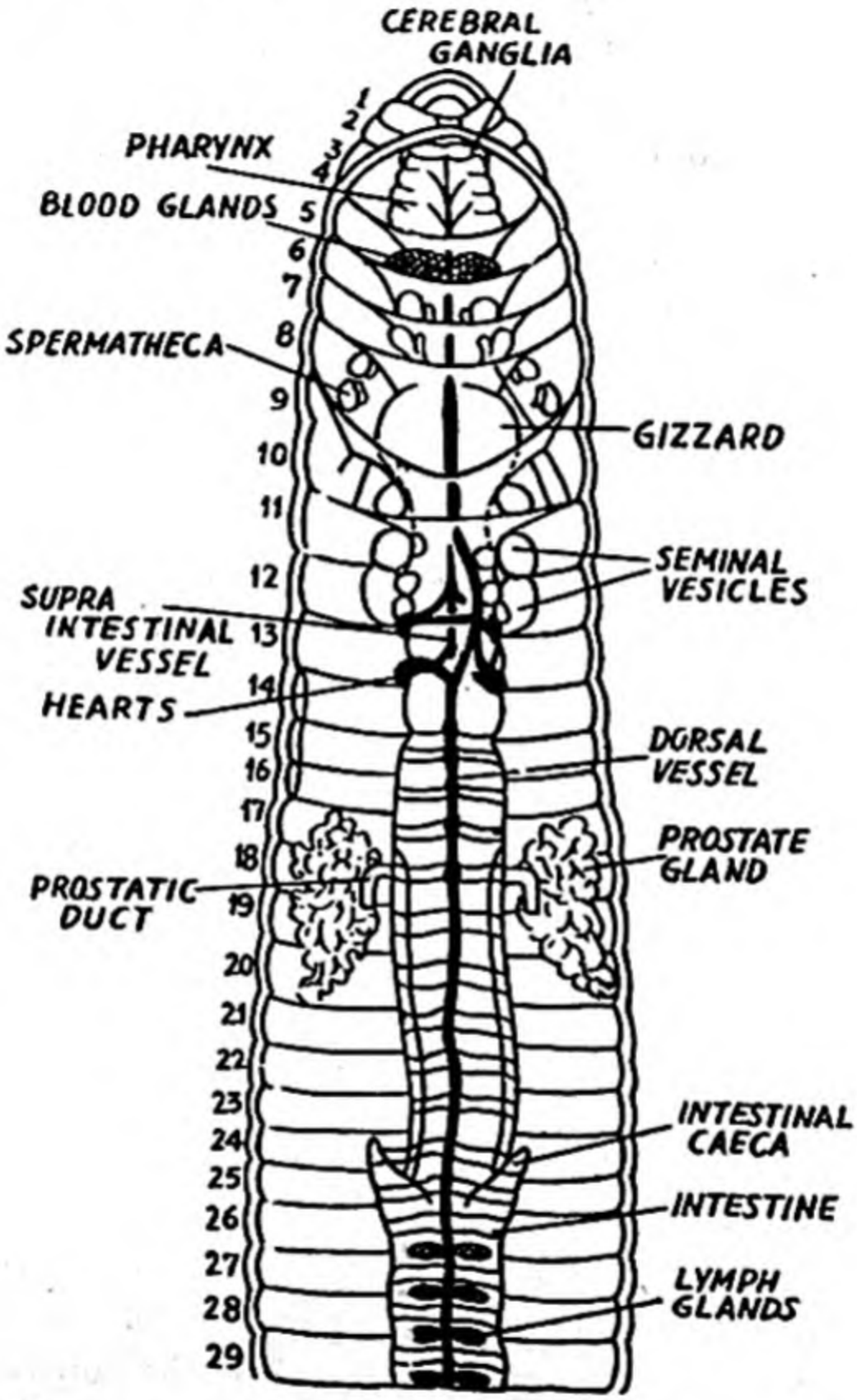


Fig: 118. A dissection of the anterior region of the body of the earthworm. (After Bahl).

The pharynx is followed by the *oesophagus* which extends from the fifth to the end of the fourteenth segment. In the

eighth segment or in the eighth and ninth, when the septum between these two segments is absent, the oesophagus is enlarged to form an oval body, the *gizzard*. This is a hard muscular organ with thick walls. It is lined by an internal cuticle secreted by the endodermal layer of the gut.

Behind the fourteenth segment the oesophagus passes into a wide thin-walled tube, the *intestine*, which runs back straight to the *anus*. In the twenty-sixth segment the intestine gives off a pair of conical outgrowths, of unknown function, called the *intestinal caeca*. They extend forwards through three or four segments. The dorsal wall of a considerable part of the intestine is produced inwards into a longitudinal ridge, known as the *typhlosole*, which increases the absorptive surface of the intestine. In the last twenty-three to twenty-five segments the intestine has no typhlosole. The terminal portion of the gut is the *rectum*, which opens to the exterior through the *anus*.

The wall of the alimentary canal consists of (1) an outer peritoneal layer, (2) a layer of longitudinal muscle fibres, (3) a layer of circular muscle fibres, and (4) an inner endodermal lining. The peritoneal cells of the intestine and rectum, and a considerable part of the oesophagus, contain minute yellow granules and are, therefore, known as *yellow chloragogen cells*. They take out waste products from the blood-capillaries of the gut and drop off into the coelom from where they are carried to the outside through the nephridia or the dorsal pores. They are, thus, excretory in function.

The food of the earthworm consists chiefly of bits of leaves and other organic matter contained in the soil which is swallowed by the worm in large quantities. By the contraction of the muscles passing from the pharynx to the body-wall the pharyngeal cavity is enlarged and food particles are drawn into the buccal cavity by a sucking action. The salivary secretion of the pharyngeal mass contains a proteolytic enzyme which starts the digestion of proteins In the gizzard the food is broken up

into fine particles by the grinding action of this organ. The sand particles contained in the soil probably aid in this process. The digestion is completed in the intestine which secretes a digestive juice containing a number of enzymes. They act on the different kinds of food-stuffs. The proteins are converted into peptones, the starch into sugar and the fats are decomposed into their constituents. The digested food is absorbed through the wall of the intestine. The undigested part of the earth is expelled through the anus as castings.

Respiratory System. In the earthworm there are no special respiratory organs, such as the gills or lungs, but respiration is carried on by the skin which is thin and transparent, with a rich blood supply. The exchange of gases takes place only when the skin is moist. If it dries up the worm dies due to lack of oxygen. The skin is kept moist by (1) the mucus secreted by its glandular cells, (2) the coelomic fluid which oozes out of the body through the dorsal pores and (3) the damp earth in which the animal lives. The oxygen from the atmosphere becomes dissolved in these fluids and passes into the blood through the membranous skin while the carbon dioxide in the blood passes out. The oxygen combines with the haemoglobin in the plasma and is carried to various parts of the body.

Blood Vascular System. The blood vascular system consists of four pairs or tubular "hearts" and a series of blood vessels, containing red blood. The red colour of the blood is due to haemoglobin which, however, is not contained in the corpuscles but is dissolved in the plasma. The corpuscles are colourless and nucleated. The arrangement of blood vessels behind the fourteenth segment differs a great deal from that in the first fourteen segments. It is, therefore, convenient to describe the vascular system in two parts.

Arrangement of Blood-vessels behind the Fourteenth Segment. The vascular system in this region (Fig. 119)

consists of three longitudinal trunks, namely, the dorsal, ventral and subneural, and a number of small branches. The blood flows forwards in the dorsal vessel and backwards in the ventral and subneural vessels.

The *dorsal vessel* is the largest of the three blood-vessels. It lies in the mid-dorsal line just above the alimentary canal, running along the whole length of the animal. It has muscular walls and is rhythmically contractile, the waves of contraction driving the blood forwards. The dorsal vessel, in each segment, receives two pairs of *dorso-intestinal vessels* which are connected ventrally with two pairs of *transverse vessels*, encircling the gut The transverse vessels collect blood from the intestine. The dorsal vessel also receives, just before piercing each septum, a pair of *commissural vessels* which arise ventrally from the subneural vessel and run upwards along the posterior face of the septum. They collect blood from the nephridia and the body-wall. The dorsal vessel, thus, receives blood from the intestine through the transverse and dorso-intestinal vessels, and from the nephridia and the body-wall through the commissural vessels. No blood is distributed in this region by the dorsal vessel. A branch of the commissural, the *septo-intestinal*, however, supplies blood to the intestine.

The *ventral vessel* lies just below the alimentary canal and runs from the anterior to the posterior end of the body. As already stated, the blood in this vessel flows backwards. A number of vessels arise from it and supply blood to the intestine, septal and integumentary nephridia, and the body wall. The ventral vessel, thus, is the chief distributing channel in this region.

The *subneural vessel* is a slender vessel lying in the mid-ventral line below the nerve-cord. It extends from the posterior end of the body to the fourteenth segment. The blood in it flows backwards. The subneural vessel collects blood from the ventral region of the body-wall and the nerve-cord

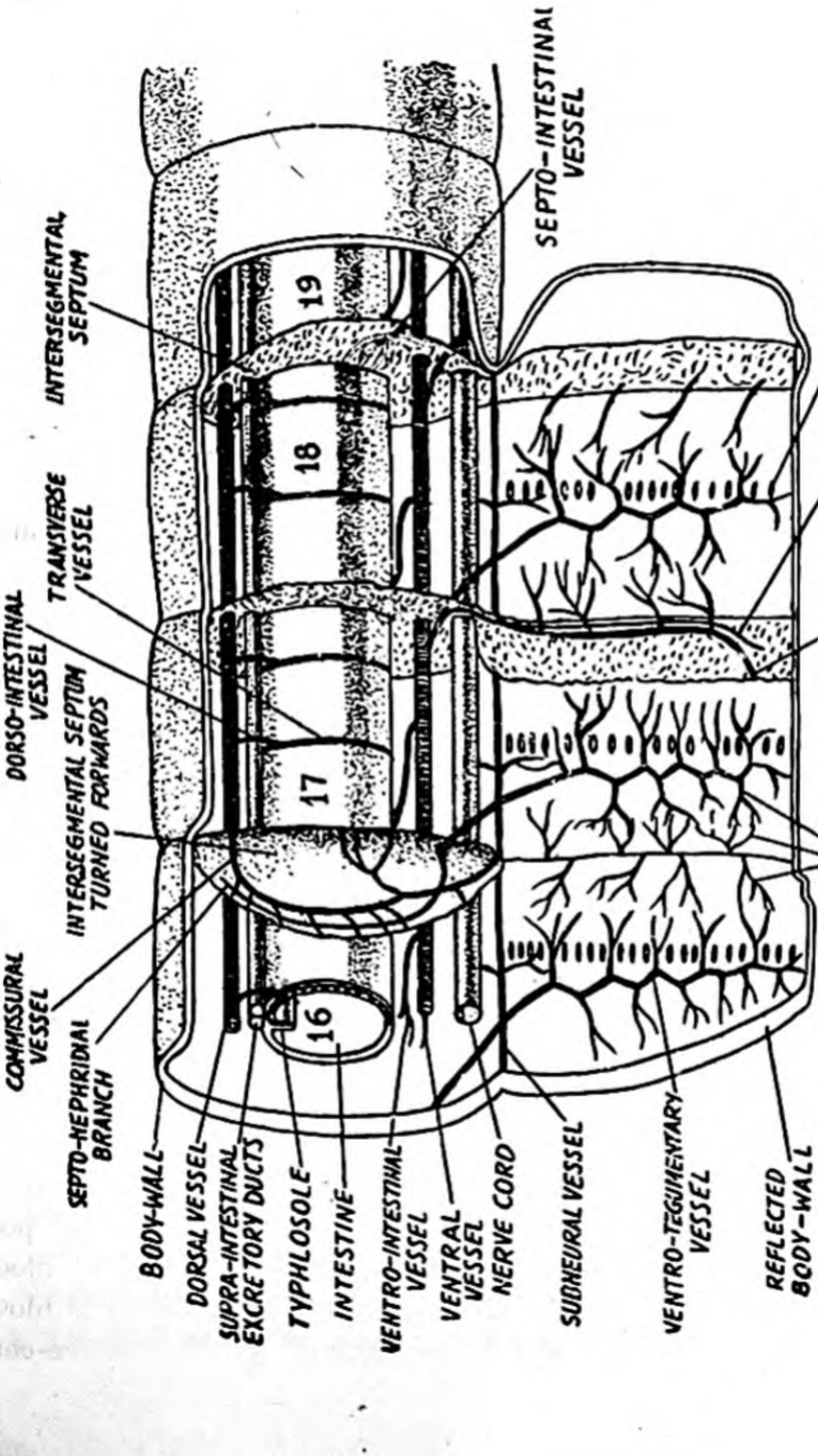


Fig. 119. A diagrammatic representation of the vascular system of an earthworm in the region of the body behind the fourteenth segment. Five segments are shown with the greater part of the body-wall on the left side cut and reflected, in order to expose the blood-vessels in position. (After Bahl).

and conveys it to the dorsal vessel through the paired commissural vessels. As mentioned above, the commissurable, on their

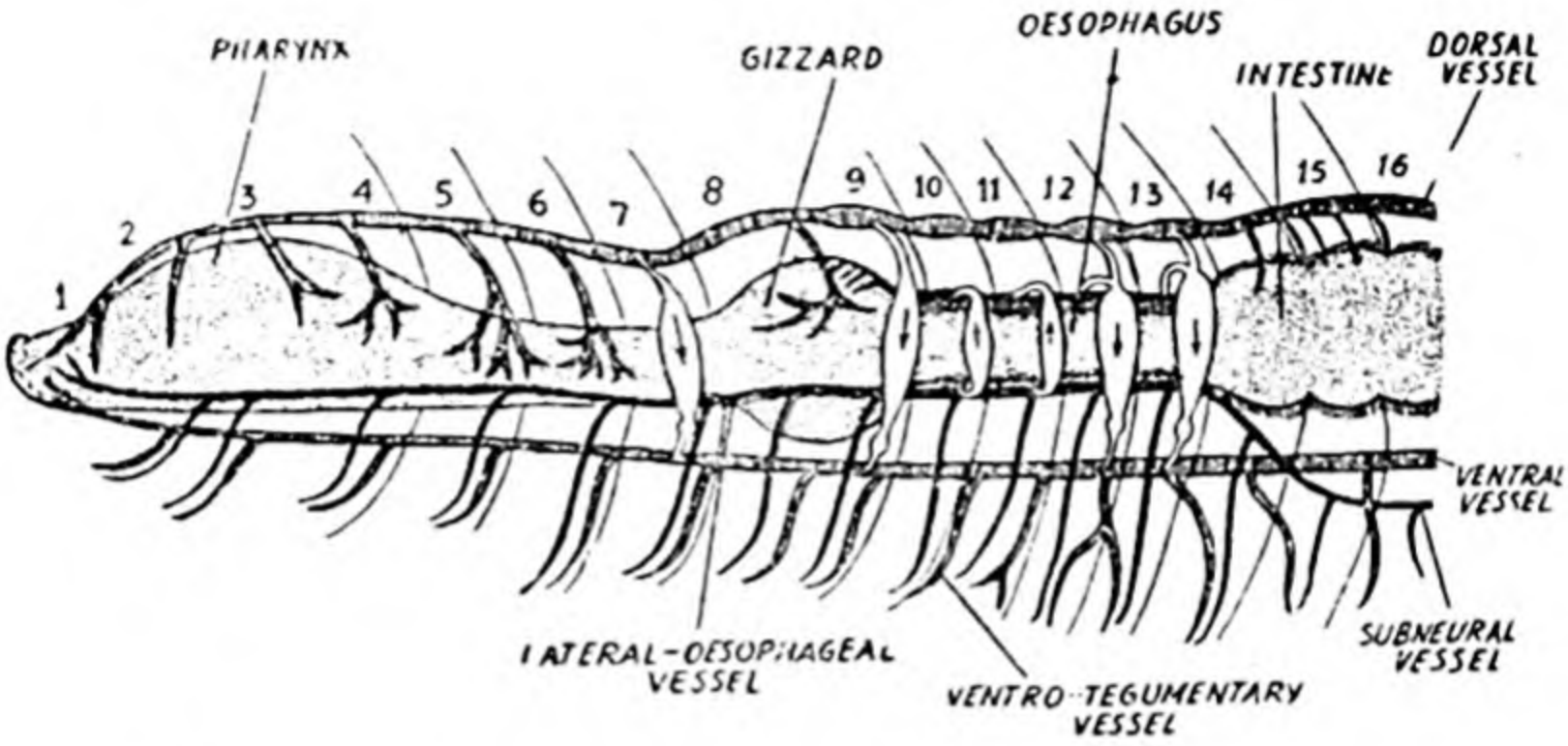


Fig. 120. A semi-diagrammatic representation of blood-vessels in the first sixteen segments of the body of an earthworm. (After Bahl).

way along the septum, collect blood from the nephridia and the body-wall. The blood from all parts of the body, in the intestinal region, is, thus, received by the dorsal vessel and pumped forwards towards the anterior end.

Arrangement of Blood-vessels in the First Fourteen Segments. The arrangement of blood-vessel in the first fourteen segments (Fig. 120) differs in many respects from that in the rest of the body. The dorsal vessel extends up to the cerebral ganglion and gives off branches to the pharyngeal mass and the buccal cavity. It also supplies blood, by paired branches, to pharyngeal nephridia, pharynx, gizzard and the oesophagus. It sends out blood into the ventral vessel through four rhythmically contractile "hearts", situated in the seventh, ninth, tweleth and thirteenth segments. The dorsal vessel, however, receives no dorso-intestinals (except a pair in the fourteenth segment) or commissurals. It should, thus, be noted that while

behind the fourteenth segment the dorsal vessel acts as a receiving channel, in the first fourteen segments it becomes a great distributing trunk. The work of collecting blood in the latter region is taken over by a new vessel, the *supra-instestinal.*

The ventral vessel, in this region, continues to be a distributing channel supplying blood to the body-wall, septal nephridia, spermathecae, seminal vesicles and ovaries. The alimentary canal, however, does not receive any blood from the ventral vessel, as the former in this region is supplied by the dorsal vessel.

The subneural vessel divides into two *lateral oesophageal vessels* in the fourtheenth segment. These two vessels run forwards along the right and left sides of the alimentary canal. They collect blood from the body-wall, septa, seminal vesicles, spermathecae and nephridia. They are connected with the supra-intestinal vessel through two pairs of circular vessels, the "*anterior loops*", situated in the tenth and eleventh segments. The supra-intestinal vessel extends from the tenth to the thirteenth segment, and collects blood from the gizzard and the oesophagus. Posteriorly it communicates with the two posterior pairs of "hearts" situated in the twelfth and thirteenth segments. The blood in the lateral oesophageals may, thus, follow one of the two routes. It may go into the ventral vessel by way of the "anterior loops", the supra-intestinal vessel and the posterior "hearts", or it may flow backwards into the subneural vessel and thence reach the dorsal vessel through the commissurals in the region of the body behind the fourteenth segment.

Excretory System. The excretory system consists of coiled tubular bodies called *nephridia.* This system, therefore, is also known as the *nephridial system.* A typical nephridium is a duct which opens at one end into the coelom by a ciliated opening, the *nephrostome,* and at the other end leads to the exterior by another opening, the *nephridiopore* The nitrogenous

waste products are collected from the coelomic fluid by the nephrostome and expelled from the body through the nephridiopore. In one kind of nephridium the inner end is closed. In another kind the duct, instead of leading to the outside, opens into the alimentary canal. The waste products in this case are discharged through the anus. Moreover the nephridia are richly supplied with blood capillaries. The glandular cells in the epithelial lining of the nephridial ducts extract waste products from the blood. These also are eliminated through the nephridiopores or the anus.

In *Pheretima* nephridia are found in all the segments of the body except the first two. There are three different sets of nephridia called, according to their position in the body, (1) integumentary, (2) septal, and (3) pharyngeal (Fig. 121).

The *integumentary nephridia* are the smallest of the three types. They are attached to the inner side of the body-wall. There are 100—250 nephridia in each segment except in the fourteenth, fifteenth and sixteenth segments where they are so numerous as to form "forests" of nephridia. The integumentary nephridium has no nephrostome and is, thus, closed at the inner end. It opens to the exterior by the nephridiopore on the surface of the body.

The *septal nephridia* are attached to all the inter-segmental septa behind the fifteenth segment. They are found in two rows on either face of the septum. There are, in each coelomic compartment, 80—100 septal nephridia. They do not open to the exterior by nephridiopores but communicate with a pair of *septal excretory canals*, running along each septum and opening into a pair of *supra-intestinal excretory ducts* which lie in the mid-dorsal line below the dorsal blood vessel. These excretory ducts in turn open into the intestine by a minute duct in each segment. The waste products collected by the septal nephridia are, thus, discharged into the intestine to be eliminated through the anus. Such nephridia, which open into

the alimentary canal, are known as *enteronephric*, while those which open directly to the exterior, like the integumentary nephridia, are called *ectonephric* or *exonephric*.

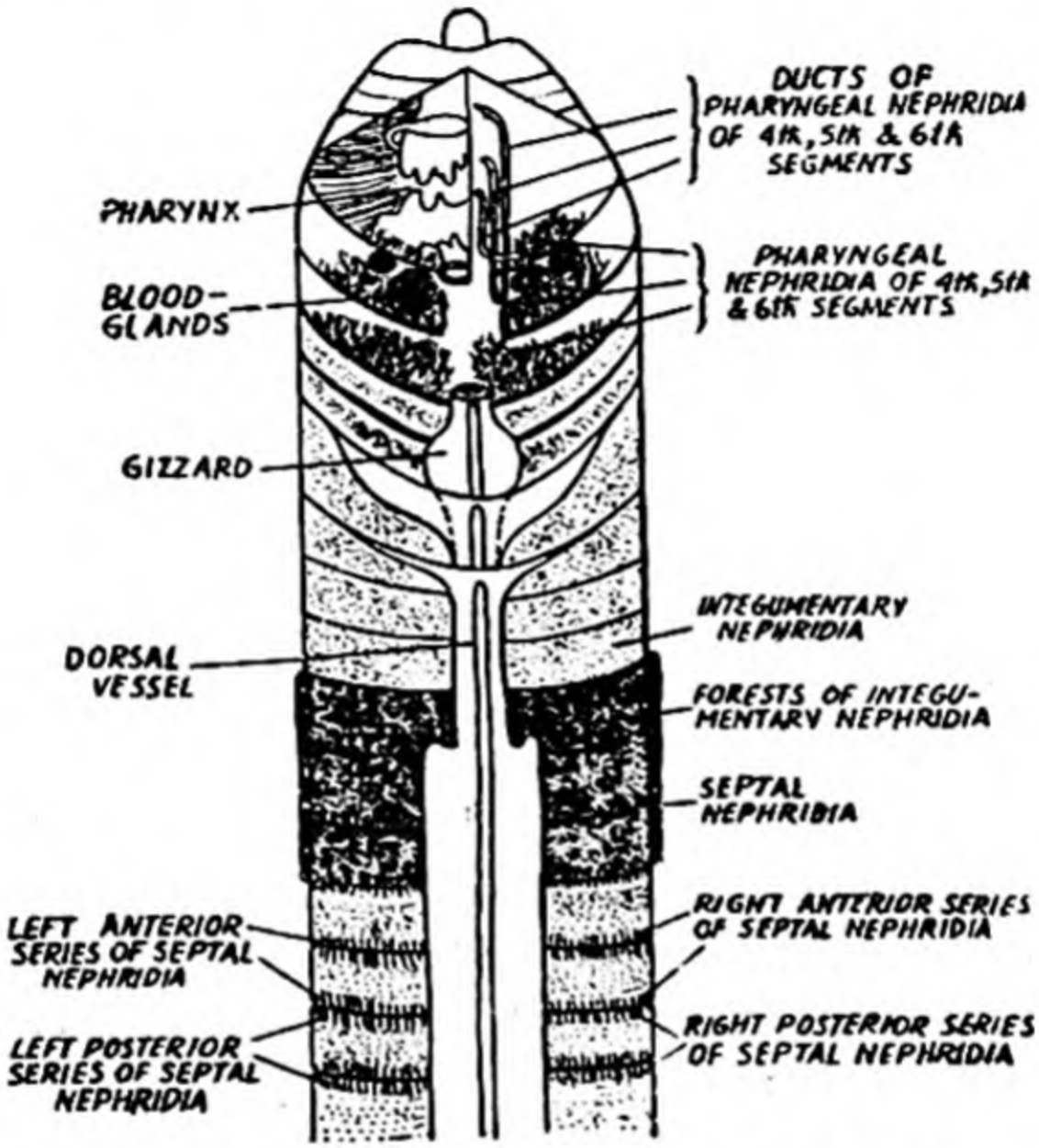

DUCTS OF PHARYNGEAL NEPHRIDIA OF 4TH, 5TH & 6TH SEGMENTS
PHARYNX
PHARYNGEAL NEPHRIDIA OF 4TH, 5TH & 6TH SEGMENTS
BLOOD-GLANDS
GIZZARD
INTEGUMENTARY NEPHRIDIA
DORSAL VESSEL
FORESTS OF INTEGUMENTARY NEPHRIDIA
SEPTAL NEPHRIDIA
RIGHT ANTERIOR SERIES OF SEPTAL NEPHRIDIA
LEFT ANTERIOR SERIES OF SEPTAL NEPHRIDIA
RIGHT POSTERIOR SERIES OF SEPTAL NEPHRIDIA
LEFT POSTERIOR SERIES OF SEPTAL NEPHRIDIA

Fig. 121. The general plan of the nephridial system of an earthworm. (After Bahl).

A septal nephridium (Fig. 122) consists of (1) a funnel followed by a short narrow tube, (2) the body of the nephridium, and (3) the terminal nephridial duct. The funnel forms the inner end of the nephridium and bears a slit-like opening, the *nephrostome*. The funnel communicates with the body of the the nephridium by a narrow ciliated duct. The body of the nephridium consists of a short straight lobe and a long spirally twisted loop. The latter is more than twice the length of the

former and consists of two limbs, a proximal and a distal, spirally twisted round each other. The terminal nephridial

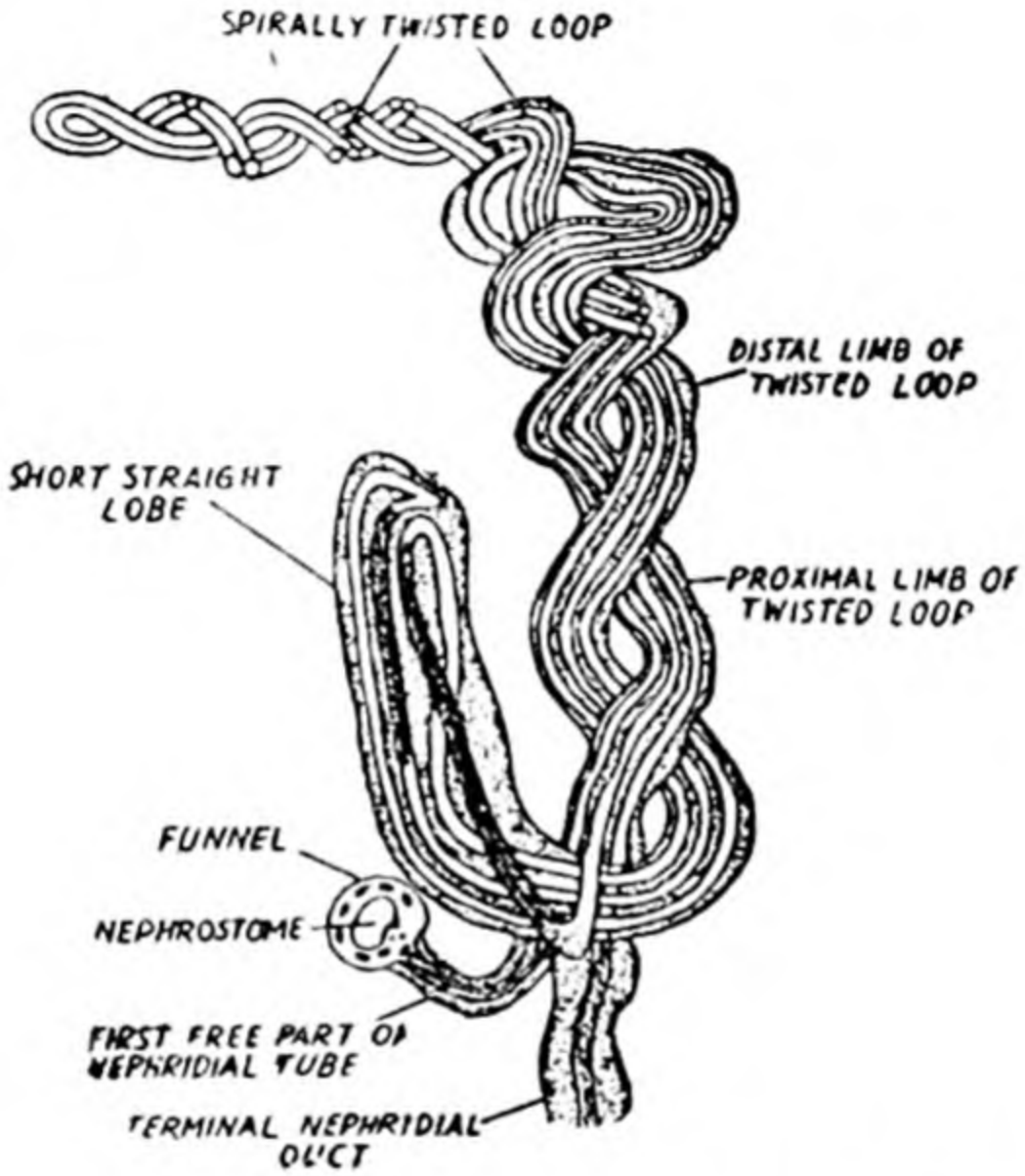


Fig. 122. A septal nephridium showing the course of the nephridial tubule. (After Bahl).

duct arises from the proximal limb of the twisted loop and opens into the septal excretory canal.

The *pharyngeal nephridia* are confined to the fourth, fifth and sixth segments They occur as three pairs of tufts or bunches, each tuft consisting of a large number of nephridia which encircle the oesophagus. The terminal ductules of adjacent nephridia unite to form ducts which unite again to ultimately form three pairs of large ducts, a pair from each of the three pairs of nephridial tufts. The pair of ducts from the nephridia of the sixth segment opens into the buccal cavity

while those from the nephridia of the fourth and fifth segments open into the pharynx. A pharyngeal nephridium, like the integumentary nephridium, has no nephrostome. The pharyngeal nephridia, like the septal nephridia, open at the discharging end into the alimentary canal and thus, belong to the enteronephric type.

Nervous System. The nervous system may be divided into the central nervous system and the peripheral nervous system. The *central nervous system* (Figs. 116, 118 and 123) consists of a pair of cerebral or supra-pharyngeal ganglia, a pair of peripharyngeal connectives, a pair of sub-pharyngeal ganglia and the ventral nerve-cord. The *peripheral nervous system* is constituted by the nerves which are given off from the central nervous system and supply the various parts of the body.

The *cerebral ganglia* lie in the third segment above the alimentary canal in the groove between the buccal cavity and the pharynx. The two ganglia are fused into a single mass which is generally known as the "*brain*". It is composed of delicate nerve fibres and nerve cells. Two pairs of nerves, given off from the cerebral ganglia, supply the prostomium and the buccal cavity. A pair of *peripharyngeal connectives* connects the cerebral ganglia with a pair of *sub-pharyngeal ganglia* in the fourth segment, the two connectives forming a ring or collar round the pharynx. Nerves arising from the connectives supply the first two segments while those arising from the sub-pharyngeal ganglia supply the third and fourth segments.

The *ventral nerve-cord* runs along the mid-ventral line of the body, extending from the sub-pharyngeal ganglia to the anal segment. The nerve-cord, which appears single, is in fact double, consisting of two longitudinal cords fused together and surrounded by a sheath. In each segment the nerve-cord bears a swelling which represents a pair of ganglia fused together. From each ganglionic swelling arise two pairs of nerves, which

contain both afferent and efferent fibres, and which are distributed to the body-wall and the viscera. The nerve-cord, like the brain, is made up of nerve fibres and nerve-cells, the latter being present in the ventral and lateral regions of the cord.

Although the earthworm is devoid of organs of special sense, it has definite reactions to various external stimuli. Its skin is highly sensitive to vibrations in the soil. The anterior region of the body is sensitive to light which is always avoided. The sense of smell is well-developed and the worm can detect the presence of food from a considerable distance. The prostomium seems to be a special organ of touch and taste. The sense of hearing, however, appears to be altogether absent.

Reproductive System. The earthworm is *hermaphrodite*, that is, both the male and the female reproductive organs are found in the same individual (Fig. 123). Self-fertilization, however, is impossible because the testes and the ovaries do not mature at the same time. The testes develop earlier than the ovaries and become atrophied by the time the latter become functional.

Male Reproductive Organs. There are two pairs of *testes* contained in the same number of *testis-sacs*, which lie in the tenth and eleventh segments ventral to the oesophagus and are exposed when the latter is removed. The testis-sacs communicate with two pairs of large whitish bodies, the *seminal vesicles*, situated on the sides of the oesophagus in the eleventh and twelfth segments. The two testis-sacs of the tenth segment open into the two seminal vesicles of the eleventh segment, while the testis-sacs of the eleventh segment open into the seminal vesicles of the twelfth segment. The testis-sacs of the same segment also communicate with each other. The testes are functional only in the young worms, becoming atrophied in full-grown specimens.

Each testis is a minute white body attached to the inner surface of the anterior wall of the testis sac, and is made up of

five to eight finger-shaped processes, containing spermatogonia or sperm mother cells. These are shed into the testis-sacs

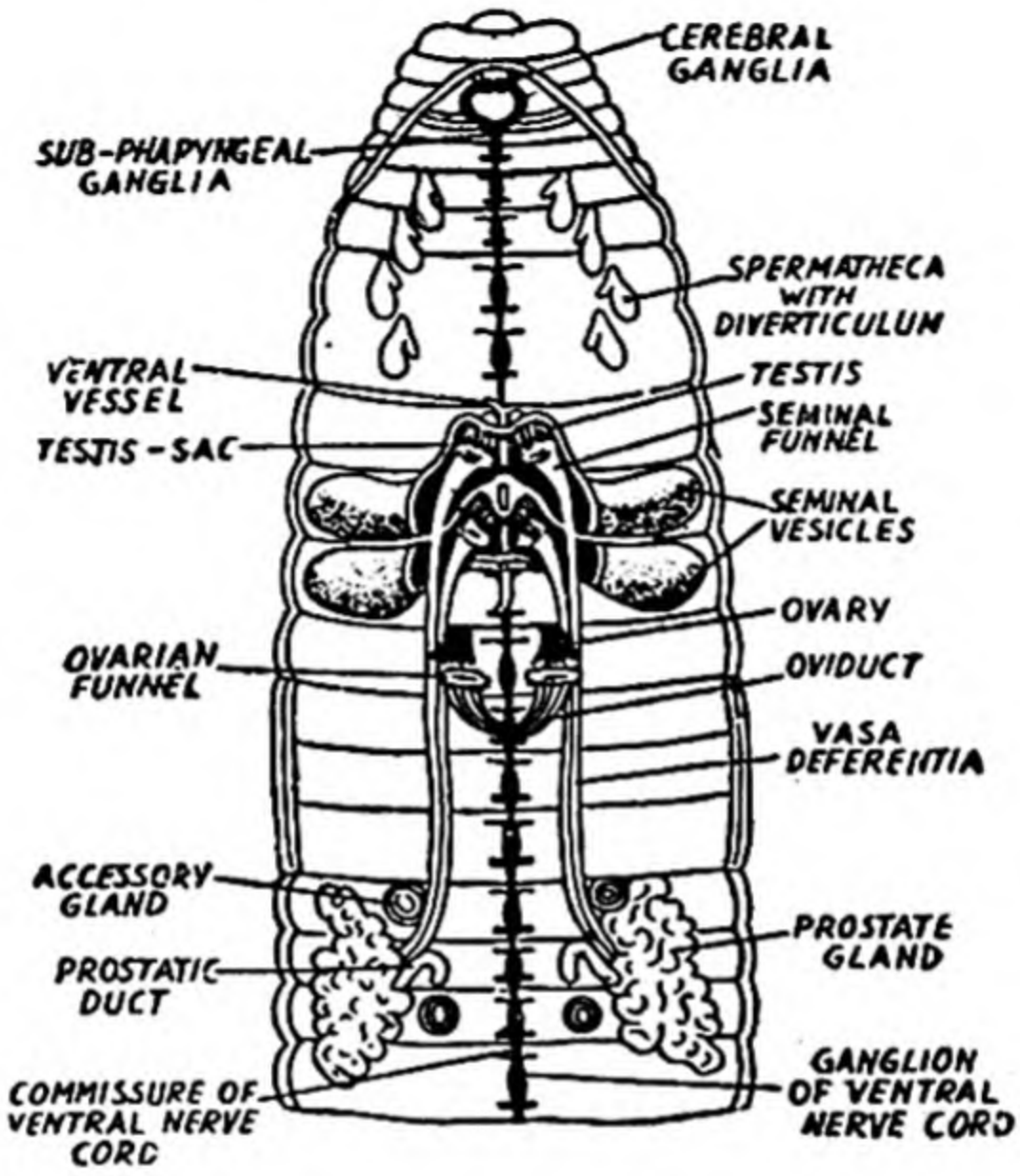


Fig. 123. A dissection of the earthworm, showing the reproductive and nervous systems (semi-diagrammatic). (After Bahl.)

from where thep pass into the seminal vesicles. Here they undergo further development and mature into spermatozoa which find their way back into the testis-sacs. Finally the sperms leave the testis-sacs through the ciliated *seminal funnels* of which there are two pairs, each funnel lying immediately behind its own testis. Each seminal funnel is continued backwards into a sperm-duct or *vas deferens*. The two vasa deferentia of either side come together in the twelfth segment

and run backwards, side by side, up to the eighteenth segment where they join the prostatic duct of their own side.

The *prostate glands* are a pair of large irregular white glands lying one on either side of the alimentary canal from the sixteenth to twenty-first segment. Each prostatic duct on emergence from the gland, is joined by the two vasa deferentia. The three ducts have a common sheath but remain separate throughout and open externally by three independent apertures at the male genital pore of their side on the eighteenth segment. Each male genital pore, thus, is in reality a group of three apertures. There are two pairs of *accessory glands*, a pair each in the seventeenth and nineteenth segments.

Female Reproductive Organs. The *ovaries* are a pair of minute bodies lying in the thirteenth segment, one on either side of the nerve-cord and attached to the posterior face of the septum between the twelfth and thirteenth segments. The basal part of each ovary is compact while the distal part consists of finger-like processes which contain ova in various stages of development.

The oviducts are two short tubes with large funnel-shaped inner openings which lie immediately behind the two ovaries. The oviducts pierce the septum between the thirteenth and fourteenth segments and unite to open to the exterior by a common aperture on the fourteenth segment. The ova, when discharged from the ovary, are received by the funnel and are conveyed to the exterior by the oviduct.

There are four pairs of *spermathecae* situated, a pair each in the sixth, seventh and ninth segments. Each spermatheca consists of a pear-shaped sac or *ampulla* and a duct leading from it. The latter gives off a fair-sized diverticulum. The spermathecae open to the exterior through four pairs of *spermathecal pores* situated laterally in the grooves between the fifth and sixth, sixth and seventh, seventh and eighth,

and eighth and ninth segments. The spermathecae store spermatozoa received from another worm during copulation.

Copulation and Cocoon Formation. Copulation takes place during the rainy season as well as in September and October, either at night or in the early morning. The process of copulation has not yet been thoroughly studied in *Pheretima* but it has been followed in detail in *Lumbricus*. It is, however, probable that the process is more or less similar in the two genera.

During copulation two young worms, with their heads in opposite directions, become closely applied to each other by their ventral surfaces in such a way that the spermathecal segments of each lie against the clitellum of the other (Fig. 124). The two worms adhere firmly to each other at these points with the aid of the setae and a glandular secretion from the clitellum. A slime-tube is secreted round each worm by the epidermis, the cavities of the two tubes being continuous with each other. There is now an exchange of seminal fluid between the two worms. Spermatozoa are shed from the male genital pores of each worm into the space between the slime-tube and the body, and carried, along two temporary lateral grooves in the skin, to the region of the clitellum. From here the sperms find their way into the spermathecae of the other worm, travelling along intersegmental grooves in this region. After this the worms separate.

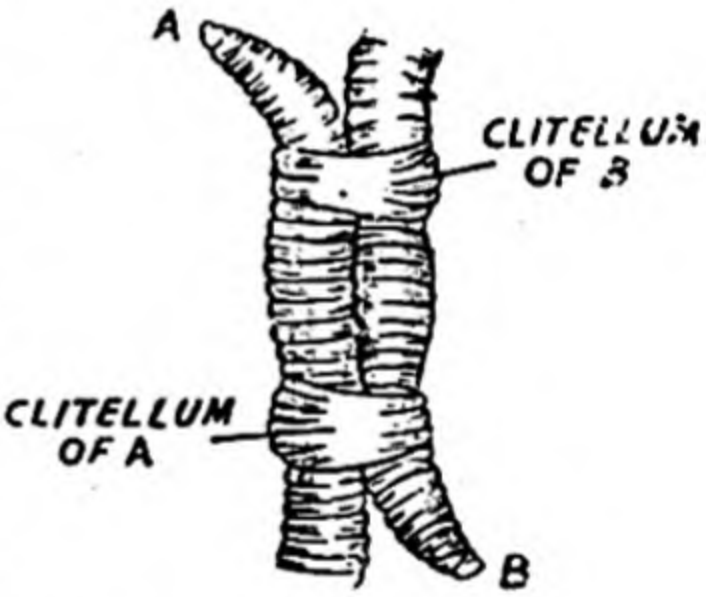


Fig. 124. Copulating earthworms

After some time, when the ovaries have matured, the worms prepare to form cocoons. The clitellum secretes a broad membranous band or girdle round itself. The girdle hardens on exposure to the air and the worm gradually wriggles back out of it. As the girdle passes over the female genital aperture and the spermathecal pores, it receives first the ova and then the sperms, and also albumen secreted by the anterior segments. The girdle is finally thrown off. Due to its own elasticity the girdle at the two ends closes up, forming a cocoon, which is laid in the earth. The fertilization of the ova by the sperms and their development takes place inside the cocoon but, as a rule, only one fertilized ovum undergoes complete development to give rise to a new individual. The albumen in the cocoon serves to provide nourishment to the growing embryo.

Regeneration. The earthworm possesses considerable power of regeneration, though not to the same extent as *Hydra*. If a worm is cut into two halves the head ends will grow a new tail and the tail end a new head. The earthworm is able to replace lost parts because all the segments of the body are similar to one another. Practically each segment contains some part of all systems in the body except the reproductive system which is confined to certain segments in the anterior region.

CHAPTER XXIII

THE COCKROACH

There are two species of cockroach common in India, *Periplaneta orientalis* and *Periplaneta americana*. The latter can be distinguished from the former by its larger size, lighter colour and the wings, which are present in both sexes, extending beyond the posterior end of the body. In the former species the wings are rudimentary in the female and are shorter than the body in the male. Both species are found in kitchens, food markets, grocery shops, railway wagons and other similar places. They are nocturnal in habits, that is they are active at night when they feed on all sorts of animal and vegetable substances.

External Characters. The body (Fig. 125) is ovoid in form and is flattened dorso-ventrally. It is covered with a sheet of chitin made of a large number of pieces or *sclerites*. The chitinous covering forms the exoskeleton of the animal. The body consists of three distinct regions—the *head*, *thorax* and *abdomen*.

The *head* (Fig. 126) is a pear-shaped structure and lies at right angles to the long axis of the body. The exoskeleton of the head is composed of a number of sclerites which unite to form a compact *head-capsule*. There is an *epicranium* above, consisting of two *epicranial plates* separated from each other by an *epicranial suture*, a *frons* and a *clypeus* in front and two *genae* or "cheeks" at the sides below the compound eyes. The *labrum* or upper lip is hinged to the lower edge of the clypeus. On either side of the head is a large black kidney-shaped *compound eye*. Its surface is

divided into a large number of hexagonal areas or *facets*. On the inner side of each eye is a white circular area, the *fenestra*. The mouth lies at the lower end of the head covered in front by the labrum.

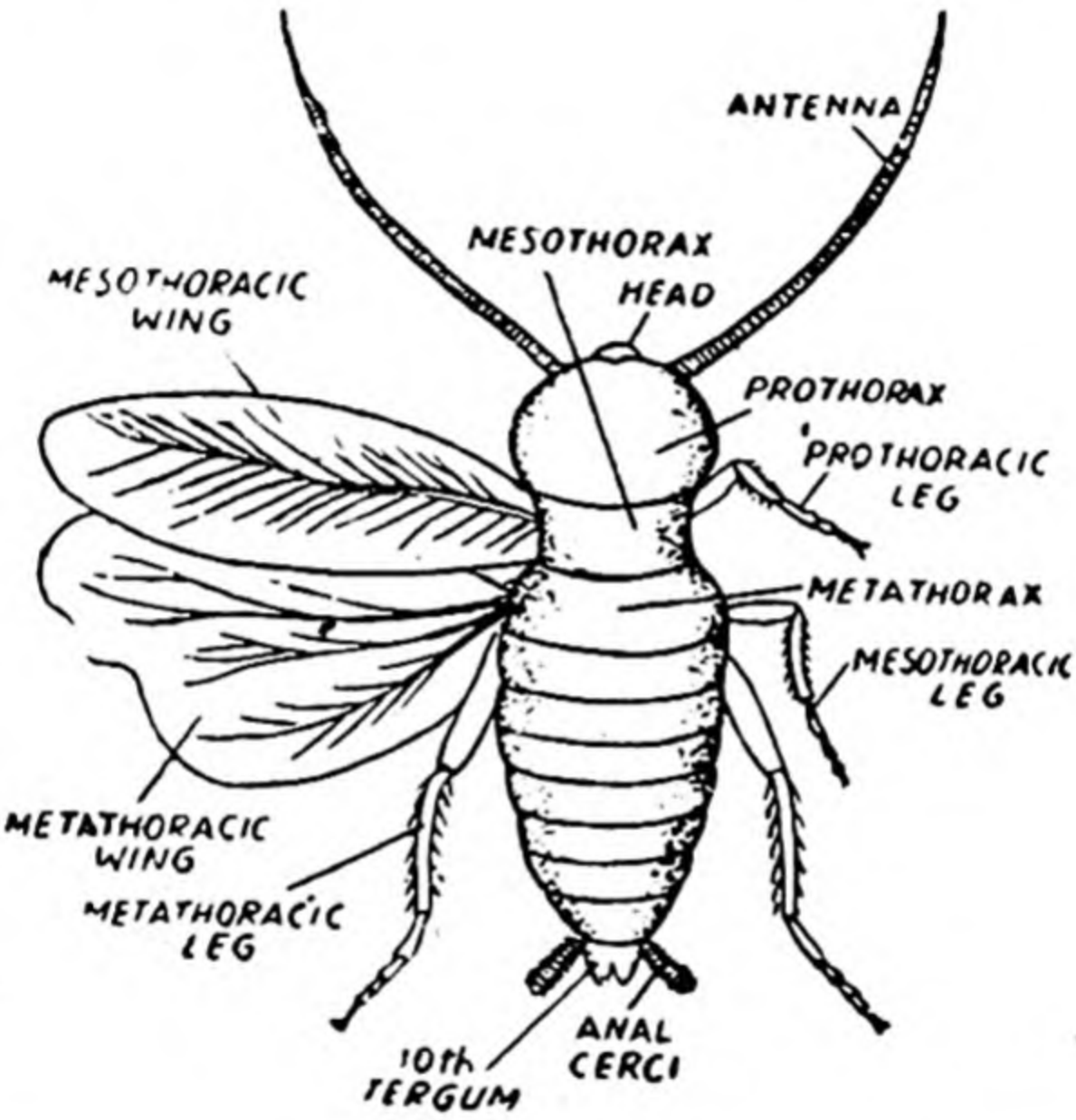


Fig. 125. *Periplaneta americana.* Dorsal view of female, wings of the right side removed.

The head bears four pairs of appendages, namely, a pair of *antennae* or feelers (Figs. 125 and 126), a pair of *mandibles* or true jaws and two pairs of *maxillae* (Fig. 127). Each antenna is a long slender many-jointed appendage articulating with the front of the head close to the inner edge of the eye. The *mandibles* are a pair of solid pieces of chitin bear-

ing teeth along their inner margins. The two jaws grind the food by working against each other in a transverse plane. Each mandible is attached to the gena of its side. The *first pair of maxillae* lies behind the two mandibles. Each maxilla

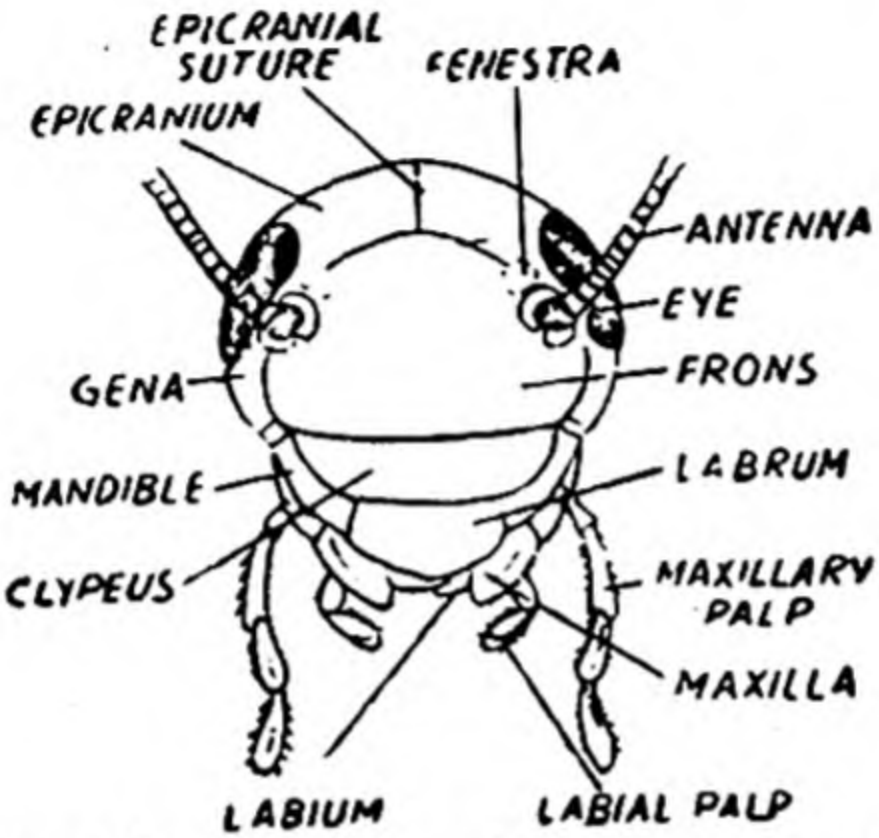


Fig. 126. Front view of the head of a cockroach.

consists of a basal protopodite of two joints, known as *cardo* and *stipes*, an outer five-jointed exopodite, known as the *maxillary palp* and an inner endopodite made up of a pointed *lacinia* on the inside and a rounded *galea* on the outside. The lacinia is the tooth part of the maxilla and helps in cutting, grasping and grinding the food. The *second pair of maxillae* is constructed on the same plan as the first, but the two maxillae are fused along the middle line to form the *labium* or lower lip. The labium consists of three parts : *sub-mentum*, *mentum* and *ligula*. The submentum and mentum represent the fused protopodites, and the ligula represents partly fused endopodites. Each half of the ligula is made up of an inner *glossa* corresponding to the lacinia of

the first maxilla, and an outer *paraglossa* corresponding to the galea. The exopodites or the *labial palps* are three-jointed, and each arises from a projection of the mentum.

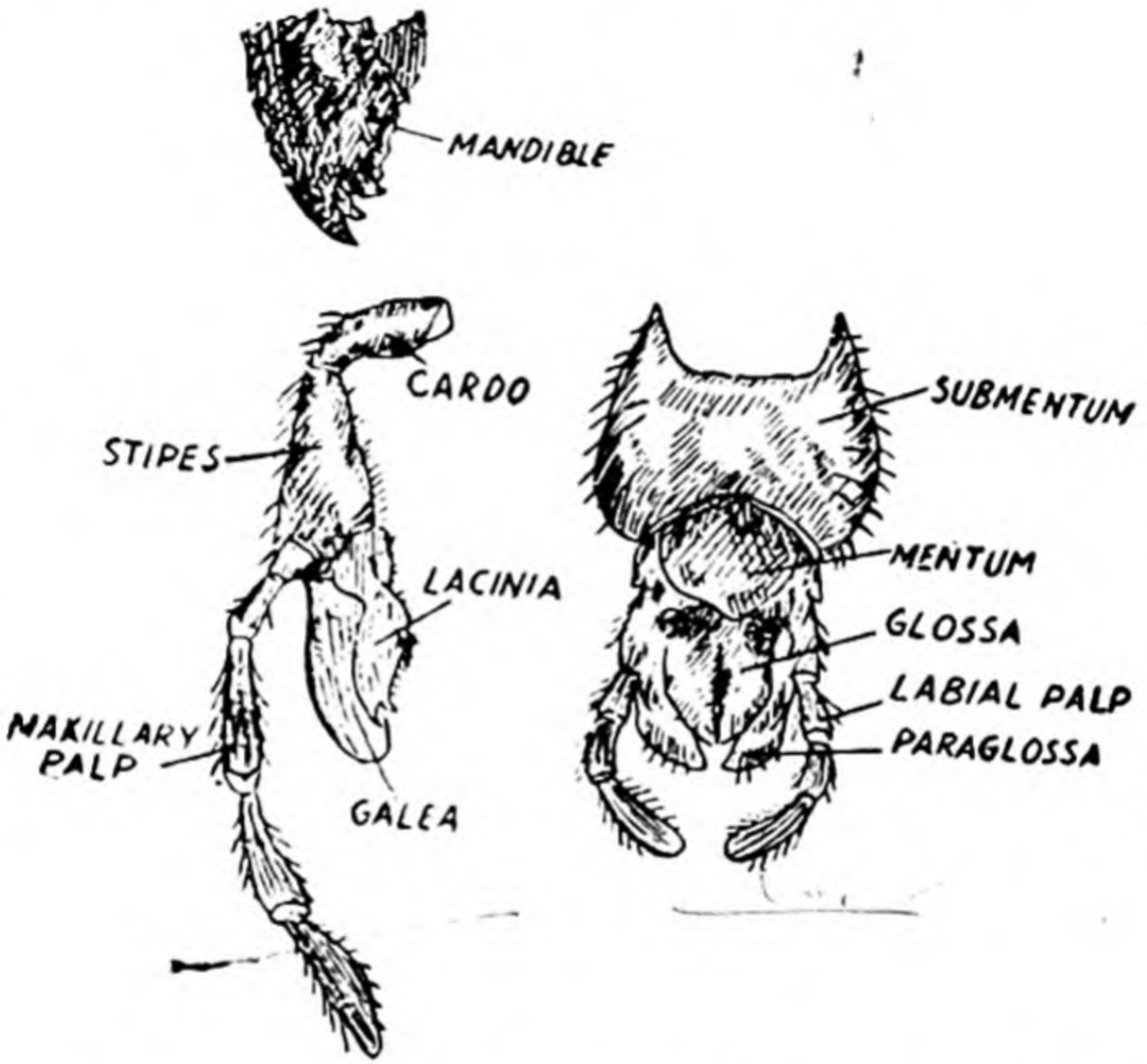


Fig. 127. Mouth-parts of the cockroach. Upper left, mandible; lower left, first maxilla; right, labium.

The *thorax* lies behind the head to which it is joined by a soft and slender neck. The thorax consists of three segments—the *prothorax*, *mesothorax* and *metathorax* (Fig. 125). The exoskeleton of each segment consists of four chitinous plates, namely, a dorsal *tergum*, two lateral *pleura*, one on either side, into a ventral *sternum*. The tergum of the prothorax is so

large as to partly cover the head and the mesothorax. Each thoracic segment bears a pair of legs. Beginning from the proximal end, each leg (Fig. 128) consists of *coxa*, *trochanter*, *femur*, *tibia* and *tarsus*. All these are single segments except the tarsus which is five-jointed. The coxa is short and stout. The trochanter is a small piece. The femur is the strongest part of the leg. The tibia is more slender than the femur. Both of them bear bristles. The tarsus is the only part of the leg which is placed on the ground when the insect is walking. It bears a pair of claws enclosing a pad-like *pulvillus*. The mesothorax and the metathorax bear each a pair of wings (Fig. 125), which are outward expansions of the body-wall strengthened by a network of thickened and hollow lines known as *veins*. The mesothoracic wings or *fore-wings* are thick and leathery and are known as *tegmina*. They cover, during rest, the metathoracic wings or *hind-wings* which are thin and membranous, and are the real organs of flight. The cockroach, however, is a running insect and rarely indulges in a flight. The hind-wings, therefore, normally remain folded like a fan under the tegmina.

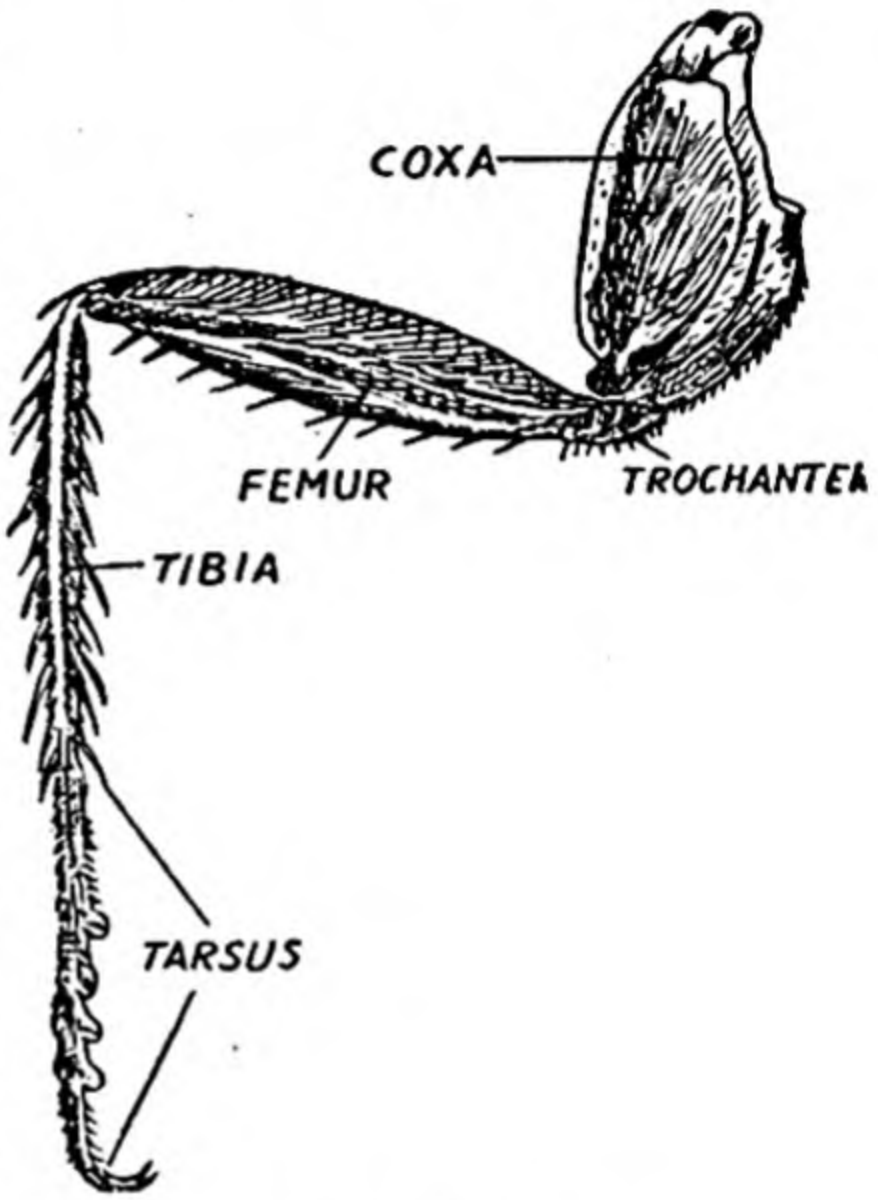


Fig. 128. Leg of a cockroach.

The *abdomen* (Fig. 125) is the terminal region of the body. It consists of ten segments, each with a tergum, a sternum and two pleura. The eighth and ninth terga are not visible from above as they are hidden under the seventh tergum (Fig. 132). In the male of *P. americana*, however, they are only partly covered and can be easily made out. The tenth tergum extends backwards beyond the end of the body and is deeply notched at the tip. The seventh sternum in the female (Fig. 133) is boat-shaped and projects backwards to completely cover the eighth and ninth sterna. It forms the floor of a large cavity, the *genital pouch*, which receives the eggs from the oviduct. A pair of many-jointed spindle-shaped appendages, the *anal cerci*, arises from beneath the tenth tergum in both sexes. In the male the ninth sternum bears a pair of slender unjointed appendages, the *anal styles*. The *anus* lies below the tenth tergum between a pair of chitinous plates, the *podical plates*. The *genital pore* is situated below the anus, surrounded by a complicated set of chitinous processes, the, *gonapophyses*. They assist in the act of copulation in the male and egg-lying in the female. There are ten pairs of *stigmata* or openings of the respiratory tubes situated along the sides of the body. The first two pairs are larger than the rest and lie on the sides of the thorax between the prothorax and mesothorax, and the mesothorax and metathorax. The remaining eight pairs open on the sides of the abdomen, a pair at the anterior border of each of the first eight abdominal segments.

Digestive System. The alimentary canal (Fig. 129) consists of three distinct regions, namely, the *stomodaeum* or *foregut*. the *mesenteron* or *mid-gut* and the *proctodaeum* or *hind-gut*. The stomodaeum and the proctodaeum are formed during the development of the embryo, by the invagination of the anterior and posterior ends of the body respectively.

They are both, thus, lined by cuticle which is ectodermal in origin and is continuous with the exoskeleton covering the body. The mesenteron alone is lined by endoderm and is the only part of the alimentary canal which is derived from the enteron of the embryo.

The *fore-gut* consists of (1) the *buccal cavity* with a tongue-like ridge on its floor, known as the *hypopharynx*, which bears the opening of the salivary duct, (2) the short and narrow *gullet* passing through the neck, (3) the large thin-walled pyriform *crop* extending into the abdomen, and (4) the short *gizzard* with thick muscular walls. From the inner lining of the gizzard project into its cavity six hard chitinous teeth. These can be brought together in the centre and working against one another, grind the food. Behind the teeth are bristles which act as strainers allowing only fine particles of food to pass into the mid-gut. The gizzard projects like a funnel into the *mid-gut* which is a narrow tube. It bears at its anterior end seven or eight finger-shaped *hepatic caeca* which secrete a digestive fluid. The mid-gut, being lined by endoderm, is the only part of the alimentary canal where absorption of digested food can take place. The *hind-gut* is long and coiled. It is divided into a short and narrow *ileum*, wider *colon* and a terminal *rectum*, the walls of which are longitudinally folded and which opens to the exterior by the *anus*. A large number of yellow thread-like processes, the *Malpighian tubules*, open into the alimentary canal at the junction of the mid-gut and the hind-gut. They extract nitrogenous waste products from the blood which, as we shall presently learn, flows freely in the body-cavity, and pass them into the hind-gut to be eliminated through the anus. The Malpighian tubules, thus, are the excretory organs of the cockroach.

There are two pairs of *salivary glands*, one on either side

of the crop, with a sac-like *reservoir* between the two glands or each pair. A duct arises from each gland and the two ducts of a pair unite to form a larger duct which unites with its fellow of the other side to form a median duct. Similarly a duct from each reservoir unites with its fellow of the other

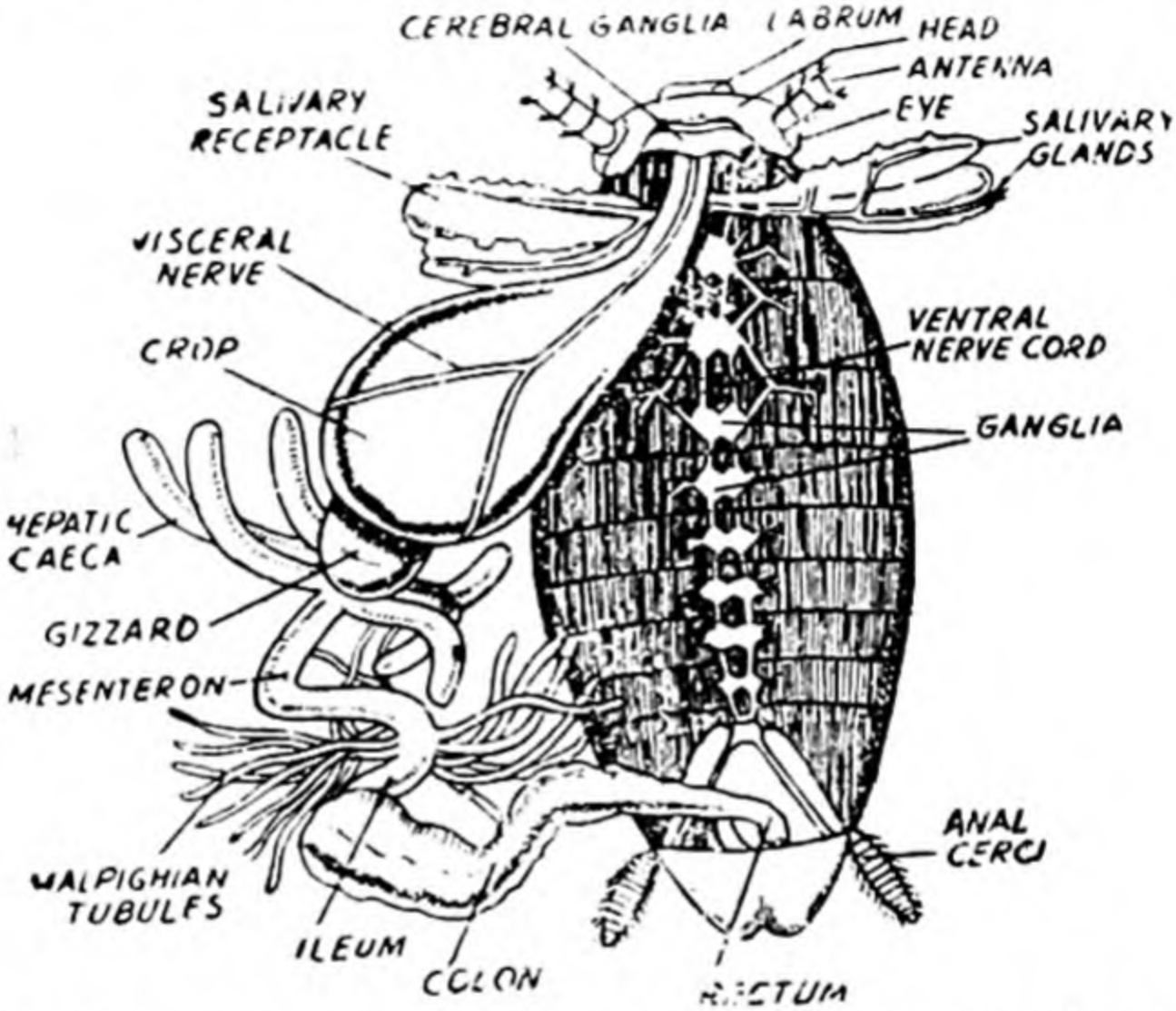


Fig. 129. A dissection of the cockroach to show the digestive and nervous systems. (From Shipley and MacBride, slightly altered).

side to form another median duct. The two median ducts then join to form a *common salivary duct* which opens into the buccal cavity on the hypopharynx. The saliva secreted by the salivary glands converts starch into sugar. The secretion of the hepatic caeca helps in the digestion of proteins and fats. The digested food is absorbed by the walls of the mid-gut and passed into the blood which everywhere surrounds the alimentary canal. Through the blood the absorbed food is distributed to all parts of the body.

Respiratory System. The respiratory system consists of innumerable branching air-tubes or *tracheae* (Fig. 130)

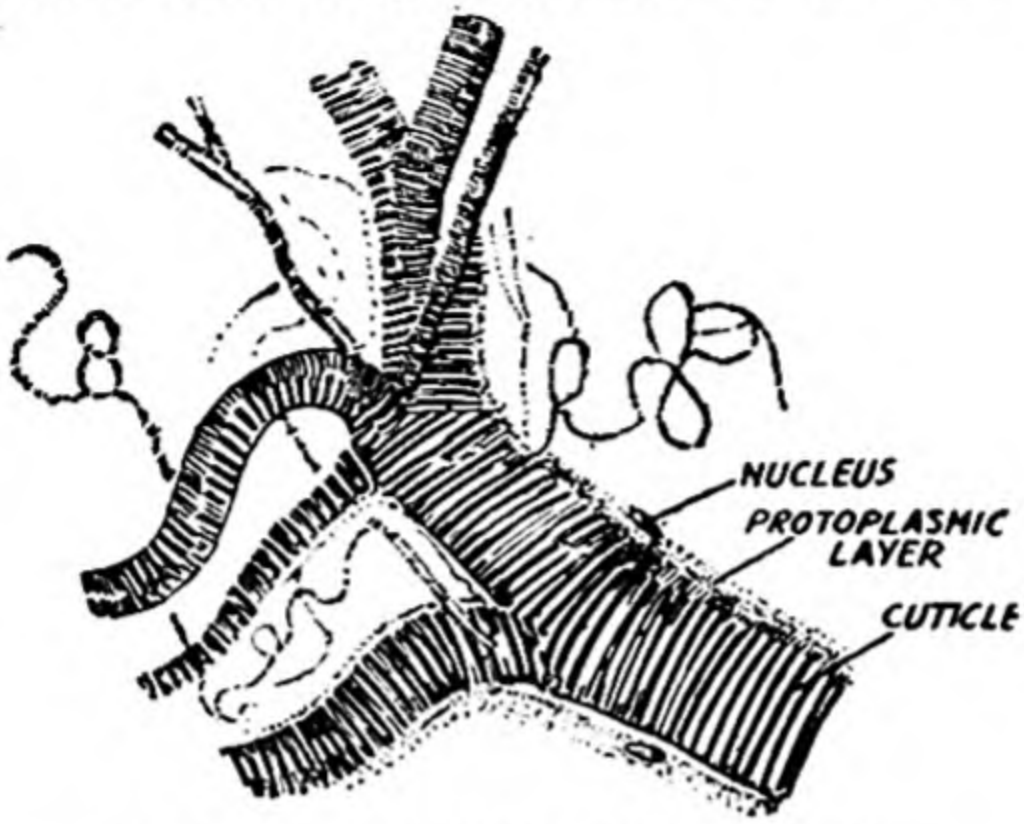


Fig. 130. The tracheal tissue of the cockroach (highly magnified).

which communicate with the outside by ten pairs of breathing holes or *stigmata* whose position on the body has already been noted. The tracheae arise as ingrowths of the skin and are thus ectodermal in origin. They are prevented from collapsing by a spiral thickening of their cuticular lining. The stigmata open into large tracheal trunks which repeatedly divide into smaller and smaller branches till they penetrate the tissues. The oxygen is thus carried directly to all parts of the body and not through the blood as in the frog and earthworm. Respiration is effected by the alternate expansion and contraction of the abdomen. These respiratory movements draw the air into and expel it from the tracheal system through the stigmata.

Blood Vascular System. The cockroach does not possess a coelom like that of the earthworm. Its body-cavity is filled with blood which surrounds and bathes all the internal organs. Such a body-cavity is known as a *haemocoele*. The

blood vascular system of the cockroach consists of a heart, an anterior aorta and the haemocoele.

The *heart* (Fig. 131) is a contractile tube closed behind but open in front. It lies in the mid-dorsal line of the abdomen and the thorax just beneath the body-wall. It is enclosed in a *pericardial sinus* which is a part of the body-cavity. The floor of the pericardial sinus is formed by a membrane, the *pericardial septum* which separates the sinus from the haemocoele. The two cavities, however, communicate with each other through apertures in the septum. The heart is divided into thirteen chambers corresponding to the number of abdominal and thoracic segments. The openings between the succeeding chambers are guarded by valves which permit the flow of blood in a forward direction only. Each chamber bears at its hinder end a pair of apertures, the *ostia*, through which the blood passes from the pericardial sinus into the heart. The valves of the ostia prevent the flow of blood in the opposite direction. The heart is continued forwards as the *anterior aorta* which opens into the haemocoele at its front end.

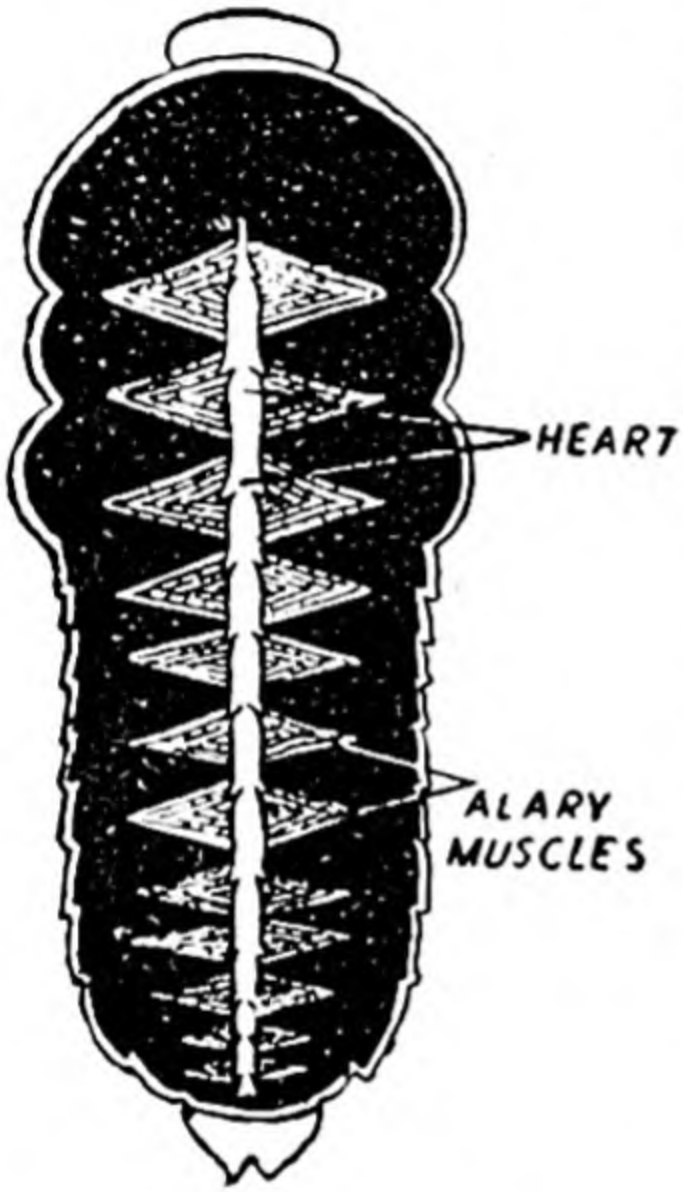


Fig. 131. Heart of the cockroach. (After Grove and Newell).

When the heart contracts the blood flows into the haemocoele through the aorta, its entry into the pericardial sinus being prevented by the valves of the ostia. Paired triangular

muscles, the *alary muscles*, arranged metamerically, are attached by their vertices to the terga and spread out in a fan-like manner over the pericardial septum. The bases of the two muscles of each pair meet in the median line below the heart. When the alary muscles contract the pericardial septum which is arched in the position of rest, becomes flattened and the cavity of the pericardial sinus is thereby enlarged. This results in the flow of blood from the haemocoele into the pericardial sinus. When the alary muscles relax the blood in the pericardial sinus is driven into the heart through the ostia.

The blood vascular system of the cockroach as described above, has neither blood vessels nor capillaries. The blood is contained in open spaces or *sinuses* which constitute the haemecoele. The blood absorbs the nutriment from the alimentary canal and distributes it to all parts of the body. The surplus products of digestion are stored in the *fat-body* which is a kind of white tissue present in the haemocoele. The blood also collects nitrogenous waste products from the organs and carries them to the Malpighian tubules to be eliminated from the body. It has, however, no respiratory function which is performed by the tracheal system. The blood is colourless and contains amoeboid cells.

Nervous System. The nervous system of the cockroach (Fig. 129) resembles that of the earthworm in its general plan. There is a pair of *supra-oesophageal ganglia* in the head, constituting the brain, which receives paired *optic* and *antennary nerves* from the eyes and the antennae respectively. A pair of short wide *circum-oesophageal connectives* arises from the brain and encircling the oesophagus unites below with a *sub-oesophageal ganglion* which is formed by the fusion of two ganglia. It supplies nerves to the mouth-parts. It is continued backwards into a double *ventral nerve-cord* which bears a ganglion in each of the first nine segments behind the head. There are, thus, three thoracic and six abdominal

ganglia. Each ganglion in reality consists of two ganglia fused together and supplies nerves to its own segment. The last ganglion is larger than the rest as it is formed by the fusion of a number of ganglia. It, therefore, supplies nerves also to the segments behind its own. A *visceral* or *sympathetic nervous system*, supplying the alimentary canal, is connected by means of nerves with the circumoesophageal connectives and the brain. Its chief ganglion, the *visceral ganglion*, is situated on the dorsal surface of the crop.

Sense-organs. The sense-organs include the compound eyes, antennae, anal cerci, and the maxillary and labial palps.

The *compound eyes* are the organs of sight. They are a pair of black kidney-shaped structures situated on the sides of the head. The surface of each eye, when examined with a lens is found to be made up of a large number of hexagonal or six-sided *facets*. A section of the eye under the microscope reveals that beneath each facet there is a long pyramidal body of complex structure, known as the *ommatidium* which is a small complete eye capable of producing an image. It is optically isolated from the other ommatidia surrounding it. About two thousand ommatidia placed side by side form the entire eye. The image formed by the entire eye, thus, is a compound one as it is made up of a large number of small images each of which is produced by a single ommatidium.

The *antennae*, *maxillary* and *labial palps* and *anal cerci* act as organs of touch. The antennae also appear to have the sense of smell and the maxillae function as organs of taste.

Reproductive System. The sexes are separate. In the male (Fig. 132) the *testes* are a pair of small bodies which lie in the fifth and sixth abdominal segments just below the terga. As the testes become reduced in size and non-functional in the adult, they can be made out without difficulty only in the young males. A delicate tube, the *vas deferens*, arises from each test is

and running backwards and downwards, opens into the *seminal vesicle* of its side. The two seminal vesicles lie close together,

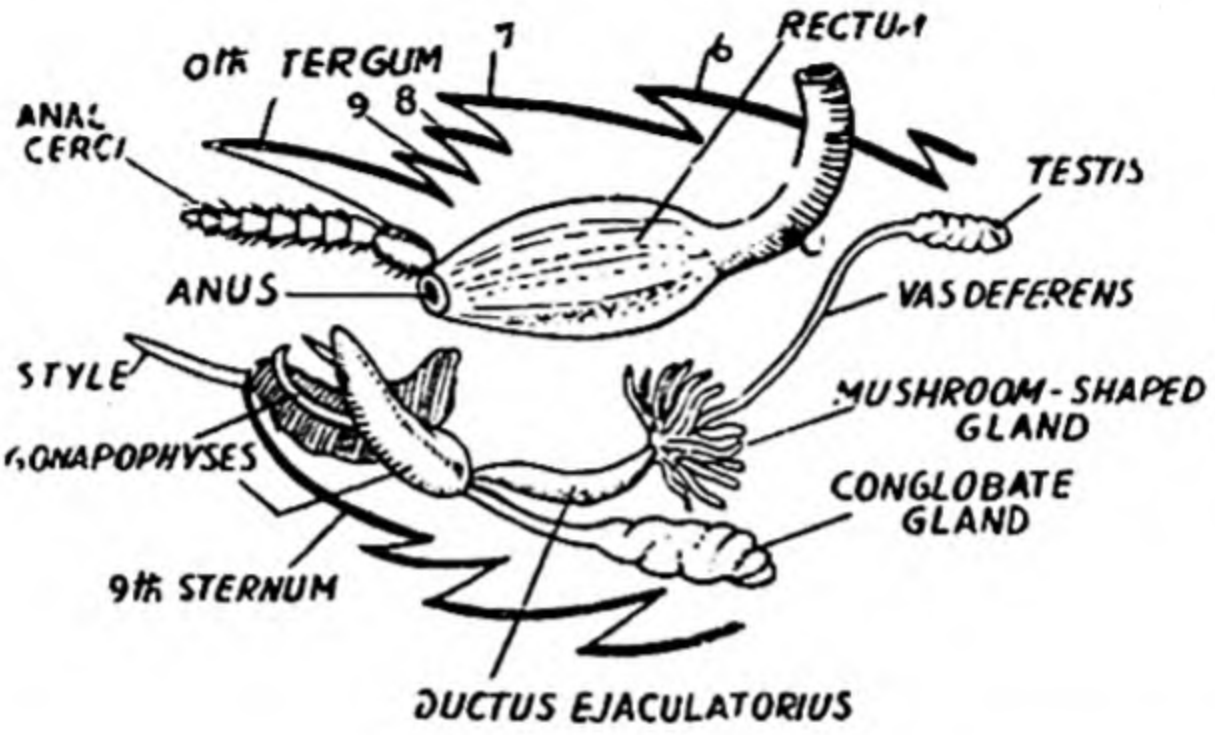


Fig. 132. Reproductive organs of a male cockroach as seen from the right side, semi-diagrammatic. (After Borradaile).

each bearing anteriorly a tuft of finger-shaped diverticula which together with the vesicles constitute the *mushroom-shaped gland*. The seminal vesicles unite posteriorly to open into a median muscular tube, the *ductus ejaculatorius* which leads to the exterior through the *male genital pore* below the anus. A large gland of doubtful function, known as the *conglobate gland*, lies below the ejaculatory duct and opens by the side of the male genital aperture. The genital aperture is surrounded by a set of chitinous processes, the *gonapophyses*, which assist in copulation.

In the female (Fig. 133) the two *ovaries* lie in the posterior part of the abdomen in the same position as the testes in the male. Each ovary consists of eight *ovarian tubes* which contain ova in various stages of development. As the ova lie in a single row they give each ovarian tube a beaded appearance. The eight tubes unite at the anterior end to form a single thread

which is attached to the dorsal body-wall. Posteriorly each ovary is continued into a short *oviduct* which unites with its

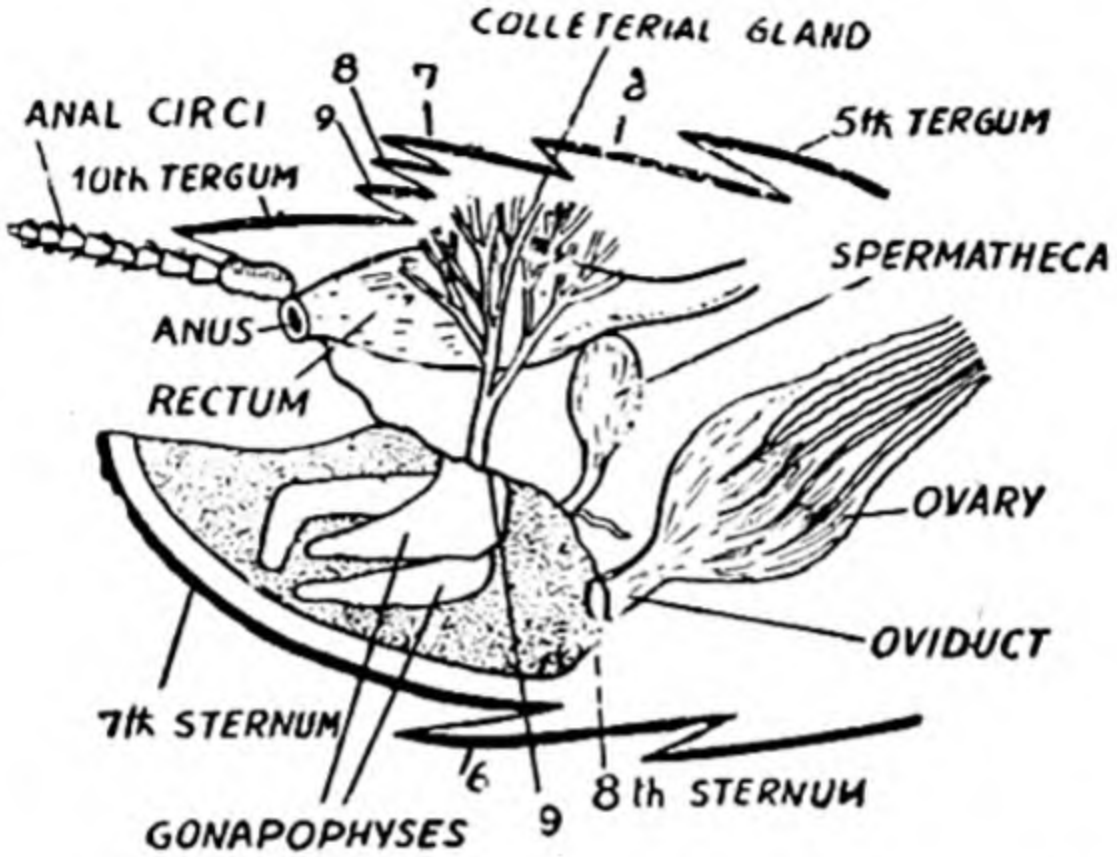


Fig. 133. Reproductive organs of a female cockroach as seen from the right side, semi-diagrammatic. (After Borradaile).

fellow of the opposite side to form a median common oviduct or *uterus*. The uterus opens into the *genital pouch* through the *female genital aperture* on the eighth abdominal sternum. The *spermatheca* opens into the genital pouch above the opening of the oviduct. A pair of branched *colleterial glands* has its openings behind that of the spermatheca. A series of chitinous *gonapophyses* is situated between the female genital aperture and the anus. They help both in copulation and egg-laying.

During copulation the mouth of the genital pouch of the female is opened by the male with the aid of the gonapophyses. The spermatozoa are then passed into the spermatheca of the female where they are stored. Sixteen ova, one from each ovarian tube, are laid at a time by the female in the genital pouch. These are fertilized by the spermatozoa shed from the

spermatheca. The fertilized eggs are then enclosed in a horny *cocoon* or egg-case formed by the hardening of the secretion of the colleterial glands. The cocoon is carried by the female in its pouch for some time and then deposited in a safe place.

When the young ones emerge from the cocoon they resemble the adults, except that they are smaller in size and have no wings. After a number of moults the wings make their appearance and the young cockroach becomes an adult.

CHAPTER XXIV

METAMORPHOSIS AMONG INSECTS

One of the characteristic, features of insects is that, in most cases, the young on hatching is morphologically different from the adult. In order to assume the adult form it has to pass through remarkable changes which are collectively known as *metamorphosis*.

Egg. All insects begin life from the egg. Insect eggs have various shapes. They may be rounded, oval, cigar-shaped, cylindrical or cask-shaped. The number of eggs laid by insects varies from a single egg to as many as one million.Th e honey-bee queen lays two thousand to three thousand eggs a day and the termite queen as many as sixty eggs a minute. In the manner of laying eggs insects exhibit a wonderful instinct, for each insect selects a particular situation where the young on hatching may find suitable food without much effort.

Moulting. The young of insects shed periodically the outer chitinous epidermis or *cuticula*. This process is known as *moulting* The cuticula, being rigid and inelastic, forms an efficient protective covering but it prevents the expansion of the body-wall which takes place as a result of growth. Therefore, as the body of the young insect grows, its cuticula becomes too small for it. When this happens a new epidermis is formed and the old one splits open usually along the back of the head and thorax. Through this slit the insect works its way out. The new epidermis, being elastic, accommodates the increased size of the insect. But it soon becomes chitinized and inelastic, and is thrown off in turn. The majority of insects moult four to six times. It should be remembered that moulting

occurs only in the young stage. The adult, except of the may-fly, does not moult and, therefore, does not increase in size. A small fly never grows into a big fly. It remains small all its life, for it belongs to a species in which the size is small.

Types of Metamorphosis.—

(A) *Development without metamorphosis (ametabolous development).*

While the majority of insects exhibit remarkable changes during the life-history there are a few in which the young insect just hatched from the egg is practically the same as the adult except for its smaller size. This type of development is known as *ametabolous development*. An example of this type of development is found in the order Thysanura (silver-fish). Those insects which have ametabolous development are collectively known as the *ametabola*. In tho ametabola there are three life-stages—*egg*, *young* and *imago* (adult).

(*B*) *Gradual metamorphosis* (*paurometabolous development*)

In several orders of insects tho young resembles the adult in general form of the body and the mode of life. The post-embryonic development in these insects is gradual without any striking morphological change except, generally, at the last moult when the wings are fully formed. The wings are developed externally during the growing period. This type of metamorphosis is known as *gradual metamorphosis* or *paurometabolous development*. This type of development is characterized by the fact that the mode of life of the young and the adult is similar and they take the same food. The orders of insects in which there is gradual metamorphosis are grouped together as the *paurometabola*. The group includes, among others, the Orthoptera (cockroaches, grasshoppers, crickets etc.), Isoptera (termites), Homopetra (cicadas, plant-lice, leaf-hoppers, etc.) and Hemiptera (true bugs). An immature stage of an insect that undergoes a gradual metamorphosis is termed a ***nymph***.

In the paurometabola there are three life-stages-*egg*, *nymph* and *imago*.

(C) *Incomplete metamorphosis* (*hemi-metabolous development*).

In the development of insects belonging to certain orders, including the Odonata (dragon-flies and damsel-flies), the changes from egg to adult are greater than in the gradual metamorphosis but not so marked as in complete metamorphosis. This type of development, therefore, has been named *incomplete metamorphosis* or *hemi-metabolous development*. In this type of development the young insect leads an aquatic life while the adult has an aerial existence. For aquatic respiration the young insect is provided with tracheal gills which disappear in the adult. The insects having incomplete metamorphosis are collectively known as the *hemi-metabola*. An immature stage of an insect that undergoes an incomplete metamorphosis is known as a *naiad*. In the hemi-metabola there are three life-stages—*egg*, *naiad* and *imago*.

(D) *Complete metamorphosis* (*holometabolous development*).

In several orders of insects the development is characterized by the fact that the young on hatching bears no resemblance in form to the adult. This type of development is known as *complete metamorphosis* or *holometabolous development*. Those orders which are characterized by this type of development are grouped together as the *holometabola*. The more important orders exhibiting this type of metamorphosis are Lepidoptera (butterflies and moths), Diptera (flies and mosquitoes), Coleoptera (beetles) and Hymenoptera (bees, wasps and ants)

The form in which a holometabolous insect leaves the egg is called a *larva*. The larval stage is the feeding stage. It is a preparation for entering the pupal stage in which feeding is suspended. Larvae of certain orders of insects have special names. Thus, the larva of Lepidoptera is known as a *caterpillar*,

that of Coleoptera and Hymenoptera a *grub*, and that of Diptera a *maggot*. In contrast to the external development of wings in the paurometabolous forms the rudiments of wings in the holometabola arise internally as ingrowths of the body-wall.

The word *pupa* means a girl. This name was given by Linnaeus as it resembled a baby wrapped up in a piece of cloth. The pupal stage is the inactive stage. The pupa lies motionless without feeding. But although the pupa is apparently at rest it is undergoing wonderful changes in the form of its body. The larva is so markedly different from the adult that its transformation involves remodelling of its entire structure. This is accomplished during the pupal stage.

As in the pupal stage there is no means of defence, many larvae either retreat to a secluded place or bury themselves in the ground where they pupate. But there are others, like the silk-worm, which spin a silken *cocoon* around their bodies. Still others use small chips of wood, or earth, in the construction of the cocoon. When the pupa is transformed into the adult, the latter breaks through the cocoon and begins to lead an active life. The pupal stage of most Diptera is passed in the last larval skin which becomes hard and serves as a cocoon. This is known as a *puparium*.

The fully developed or the adult insect is known as an *imago*. The chief purpose of the imago appears to be to perpetuate the species. For this purpose the two sexes mate and the females lay their eggs. The life of the imago is very short. Some of them live only for a day or two, like the may-flies, while most of them rarely live beyond one summer.

The life-history of a holometabolous insect, thus, consists of four life stages—*egg, larva pupa* and *imago*.

Life-history of the Mosquito. The female mosquito of the genus *Culex* (Fig. 134) lays 200—300 eggs on the surface

of stagnant water in a ditch, pond or tank. As soon as the eggs are laid she arranges them with its hind-legs to form a

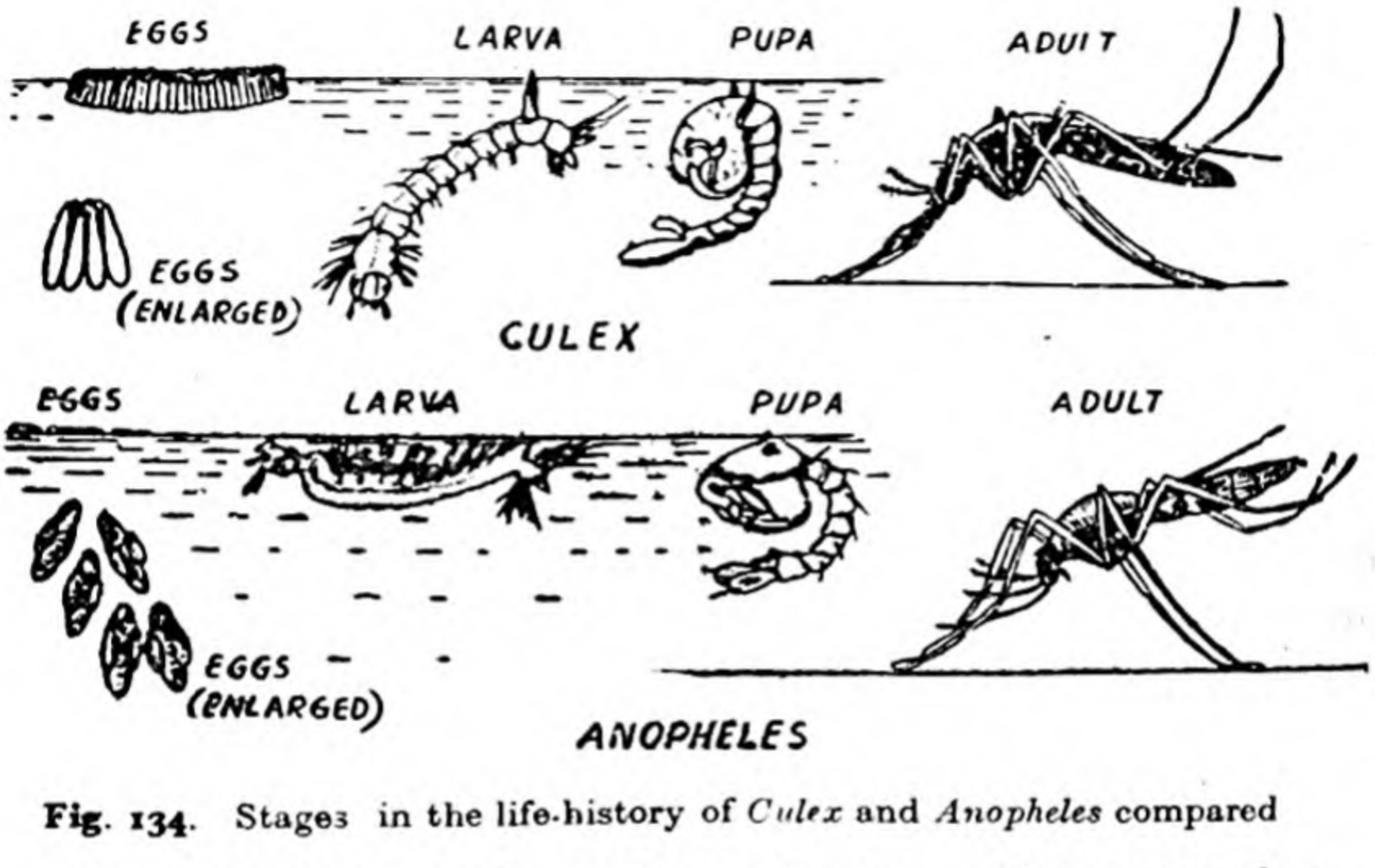


Fig. 134. Stages in the life-history of *Culex* and *Anopheles* compared

raft, which floats on the surface of water. After two or three days a small transparent larva hatches out from each egg, and begins to swim actively in the water. The body of the larva is divided into three regions, the *head*, *thorax* and *abdomen*. In the resting position the larva hangs vertically from the surface with the head pointing downwards and a small *respiratory tube* projecting obliquely upwards, from the posterior end of the body, to open just above the surface of the water. Although the larva lives in water it breathes air through the respiratory tube and must, therefore, come periodically to the surface.

After about two weeks the larva, after moulting three or four times, changes into the pupa which hangs at the surface with the head end uppermost. It breathes through two short trumpet-shaped tubes on its head, which, in fact, represents

the combined head and thorax, and is known as the *cephalothorax*. The slender abdomen is more or less bent under the cephalothorax. Through the transparent skin of the cephalothorax the rudiments of the compound eyes, antennae, wings and legs are visible. The pupa does not feed but, unlike the pupae of most other insects, is remarkable in being active. It swims by means of a pair of flaps at the posterior end of the body. After a period of one to three days the pupa is transformed into the perfect adult. The skin of the pupa now splits in the mid-dorsal line of the cephalothorax between the respiratory tubes and the imago gradually works its way out of the pupal case.

The life-history of *Anopheles* (Fig. 134) is similar to that of *Culex*, except that (1) the eggs, which are spindle-shaped, are not glued together to form a raft but float singly in a horizontal position on the surface of the water, (2) the larva also lies flat along the top of the water instead of vertically, and (3) the imago, when at rest, keeps the posterior part of the body inclined upwards. In *Culex* the body is kept parallel to the supporting surface. Moreover in *Anopheles* the wings are spotted.

Life-history of the House-fly. The house-fly (Fig. 135) lays 100—150 eggs in horse or cow-manure or any mass of decaying organic matter. The eggs are deposited by the female about half an inch below the surface. They are glistening white and each is about 1 mm. in length. Within a few hours the young hatch out from the eggs. The larva, known as a *maggat*, is a small whitish worm-like creature. It tapers to a point at the anterior end but has a broad posterior end. It has no legs or any other appendages. The larva moults twice and after four or five days changes into the pupa which, as already explained, is known as a *puparium*. It is dark brown in colour. After five or six days the pupa is transformed into the adult fly. We, thus, see that the whole life-history of the

house-fly is completed in about ten days. After this period the flies of the new generation start laying eggs. This accounts

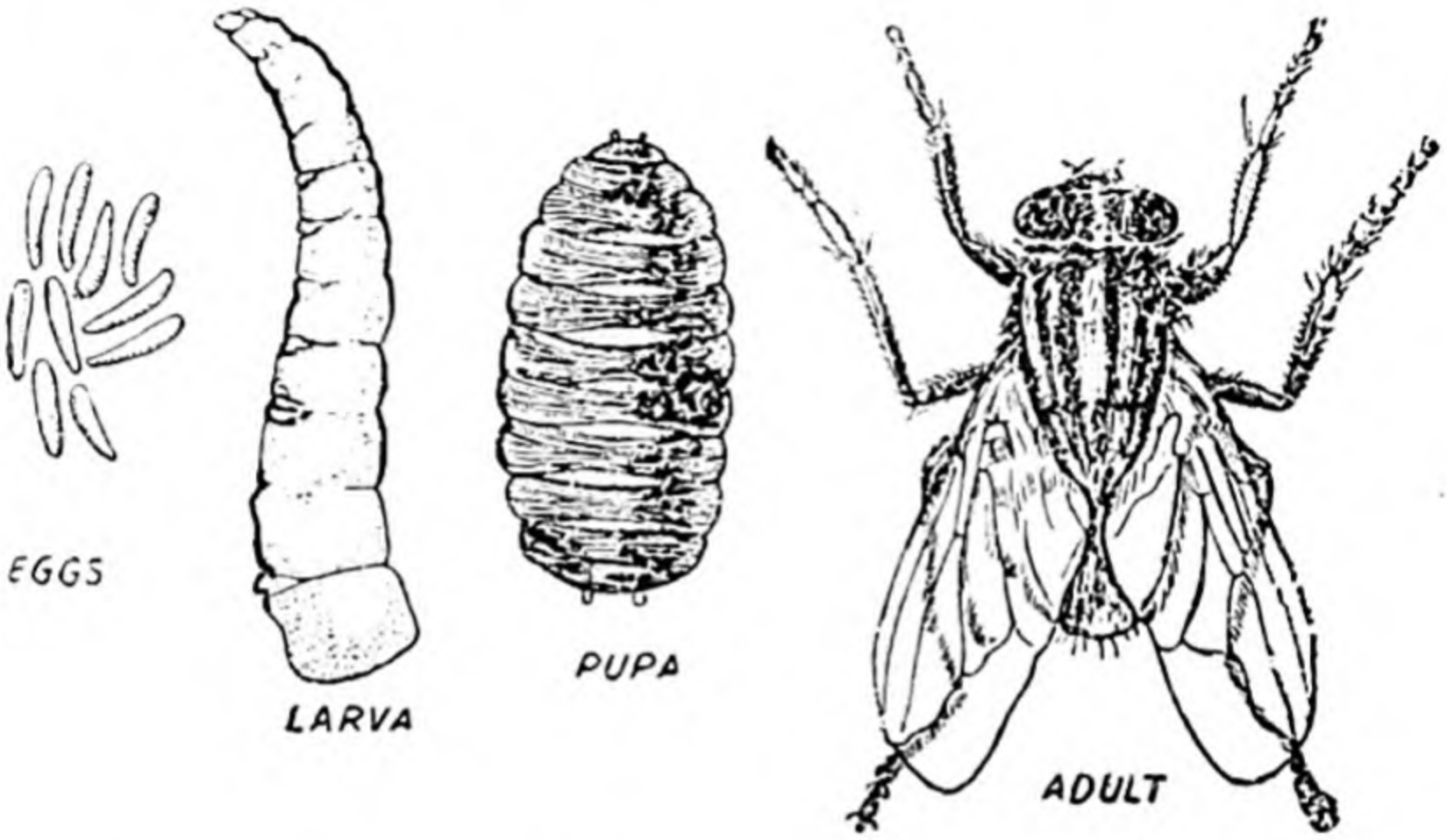


Fig. 135. Life history of the house-fly.

for the large number of flies found during the summer months.

Life-history of the Silk-moth. The silk-moth (Fig. 136) lays its eggs on the leaves of the mulberry tree. When the larvae or *silk-worms* hatch out from the eggs, a few days after laying, they start feeding on the mulberry leaves. The larva, known as a *caterpillar*, bears three pairs of jointed thoracic legs and about five pairs of unjointed stumpy abdominal legs known as *prolegs*. After a number of moults the silk-worm spins round itself a cocoon made from the secretion of silk-glands. The silk-worm is now converted into a pupa which lies enclosed in the cocoon. The larval stage lasts for about six weeks. Inside the cocoon the pupa is gradually transformed into the imago or *silk-moth* which emerges after about two weeks.

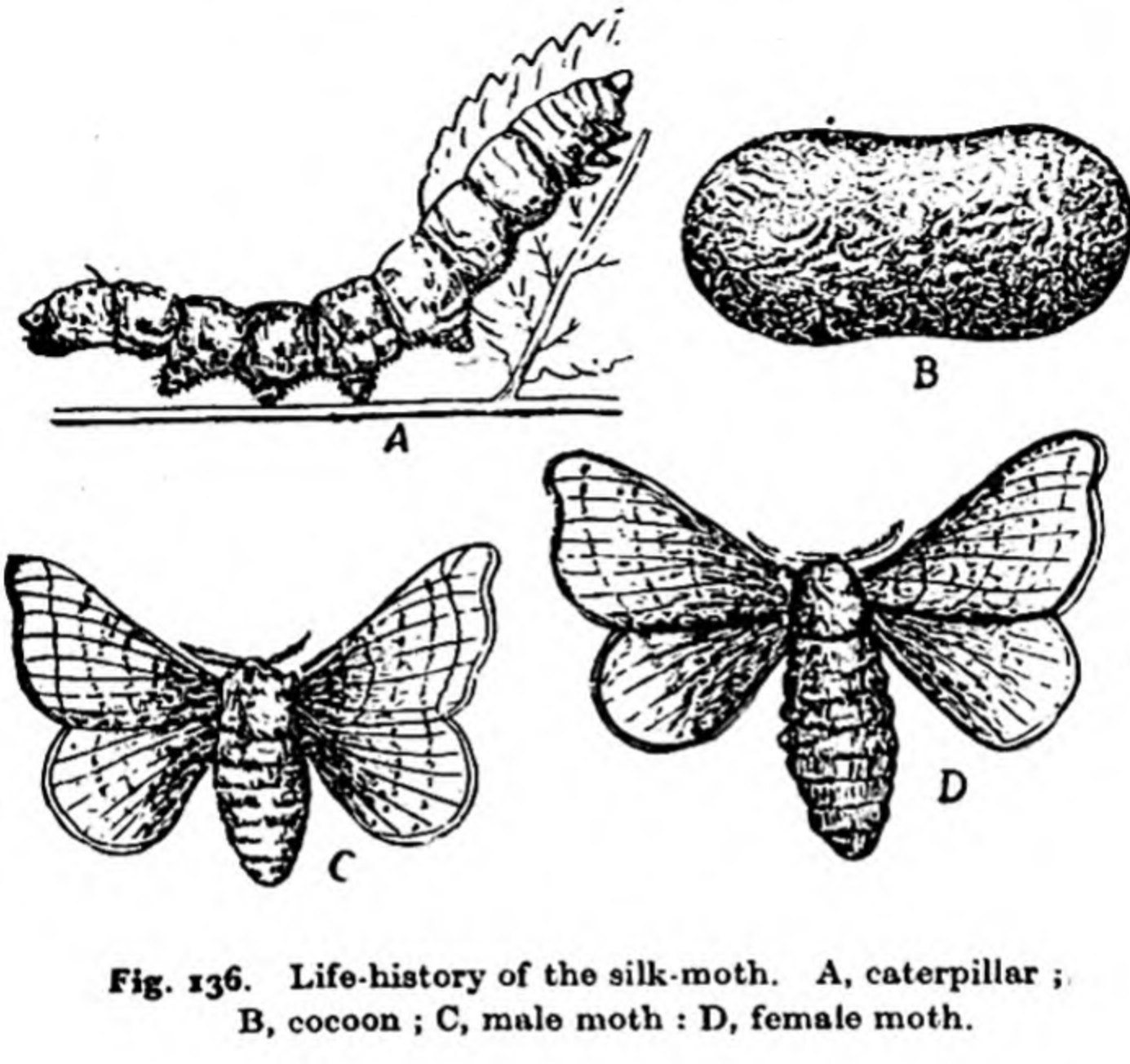


Fig. 136. Life-history of the silk-moth. A, caterpillar ; B, cocoon ; C, male moth : D, female moth.

CHAPTER XXV

THE RABBIT

Habitat and Habits. The rabbit (*Lepus cuniculus*) is a widely distributed animal. It is commonly found in India and can be easily domesticated. As a result of domestication a number of varieties have come into existence. The rabbit lives in burrows which it digs out for itself. There it sleeps at night, rests during the day, retreats for safety at the approach of danger and rears its young. The burrow has often many side-tunnels and may have more than one opening. The rabbit is herbivorous in its diet. It feeds largely on grass but is quite fond of young shoots of cereal plants and garden vegetables such as lettuce, cabbage, carrots, turnips, etc. It does not drink any water which it derives in sufficient quantity from its vegetable diet. It is a prolific breeder. It is ready to breed when six months old. There are three to eight young ones in a litter and there may be more than six litters in a year. The average life of a rabbit is seven or eight years. At birth the young ones are safely deposited at the farther end of the burrow which is previously cushioned with hair pulled out by the mother from her own body. The young ones when born are blind, deaf and hairless, but as a result of proper nursing by the mother, they soon get out of this helpless condition. The rabbit is a very timid and gentle creature. It has many enemies such as cats, foxes, rats, eagles, owls, etc. It is able to protect itself from them by virtue of its burrowing habit, feeding at dusk and vigilance in looking after its young.

External Characters. The body of the rabit (Fig. 137) is covered with hair, which in the wild variety are of a light brown colour except under the tail where they are white. In

addition to the *head* and *trunk* there is a short *tail* and a distinct *neck*. The trunk bears two pairs of limbs. Its anterior part or *thorax* is protected by ribs while the posterior part or *abdomen* is without ribs.

The *mouth* lies at the anterior end of the snout. It is comparatively much narrower than in the frog. It is bounded

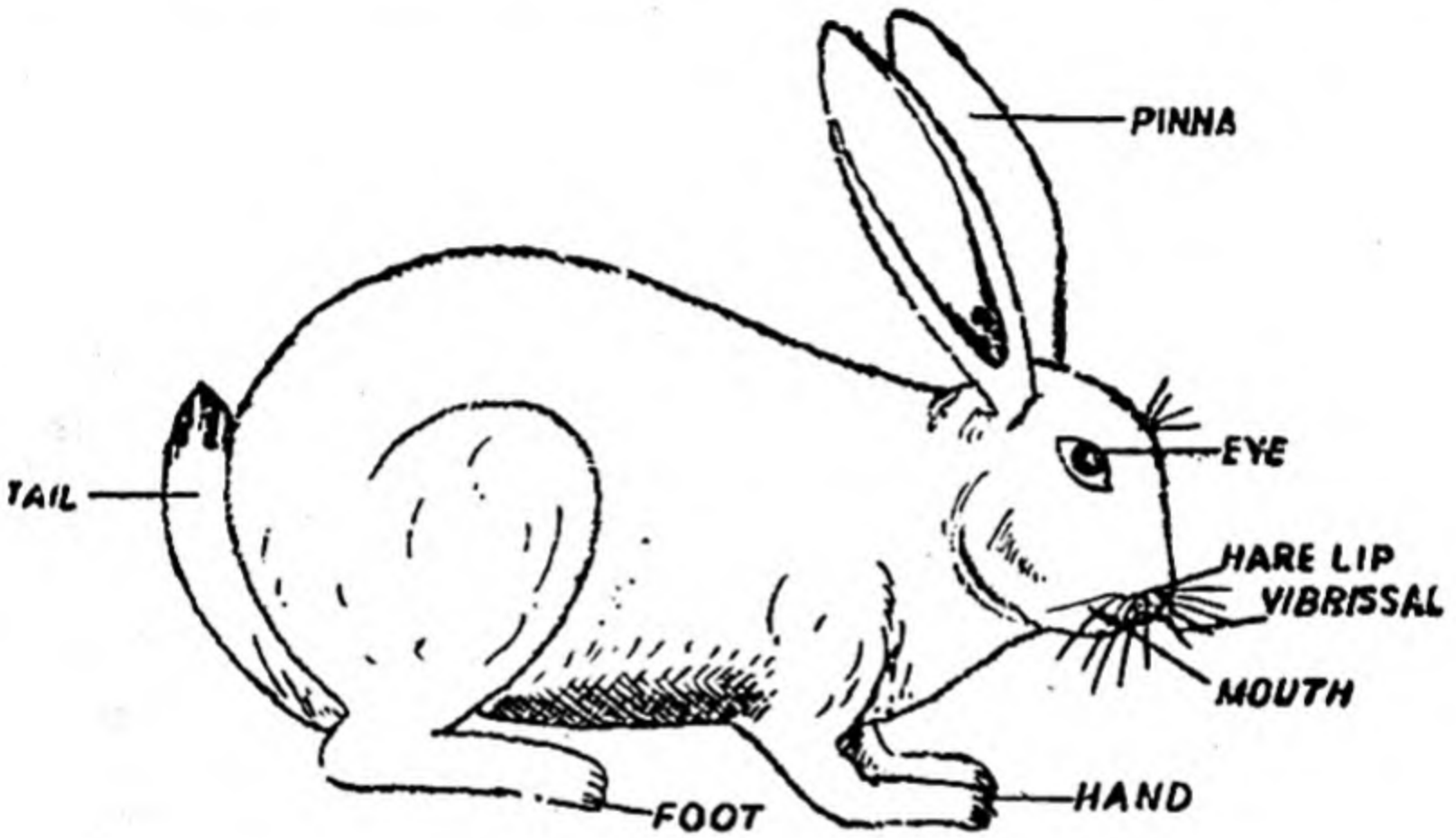


Fig. 137. External characters of a rabbit.

by the upper and lower *lips*. The former, known as *hair lip*, has a deep cleft in the middle which is continuous above with a pair of oblique slit-like *external nostrils*. The large *eyes* are placed at the sides of the head. Each eye has movable hairy upper and lower *eyelids*, like our own, and in addition a hairless third eyelid, the *nictitating membrane*, situated in the anterior corner of the eye. It can be drawn over the eye to clean the cornea. At the sides of the snout are long stiff hair, the *vibrissae*. The head bears a pair of long movable external ears or *pinnae* which enclose at their bases the ear-openings.

As there is no cloaca in the rabbit, the rectum and the urinogenital duct open directly to the outside by separate openings. The anus lies below the root of the tail and the *urinogenital aperature* in front of the anus. The space between the two is known as the *perineum*. On the sides of the two apertures, but closer to the anus than the urinogenital aperture, is a pair of hairless depressions, the *perineal pouches*, into which open the ducts of the *perineal glands* which secrete a fluid having a strong odour. In the male the urinogenital aperture lies at the tip ot an erectile cylindrical organ, the *penis*, which can be retracted within a loose fold of the skin, the *prepuce*. On the sides of the penis is a pair of pouches of the body-wall, the *scrotal sacs*, into which the testes of the adult descend during development. In the female the slit-like urinogenital aperture is known as the *vulva*. It contains anteriorly a small fleshy process, the *clitoris*, which is homologous with the penis of the male. In the female, along the ventral surface of the body, are four or five pairs of *teats* which bear the openings of the ducts of the *mammary glands* or milk-glands.

The limbs are built on the same general plan as those of the frog. The *fore-limbs* are shorter and have five digits. They are adapted for burrowing. The *hind-limbs* are much longer than the fore-limbs. They enable the animal to move about by short leaps. They have four digits, the first digit being absent. All the digits in the two limbs end in curved horny claws. The limbs of most of the air-breathing vertebrates have basically five digits, though one or more of them may be missing. Such limbs are known as *pentadactyle*.

Skin. The structure of the skin of the rabbit (Fig. 138) is different in many respects from that of the frog, for the rabbit is a warm-blooded animal and its skin does not serve as an organ of respiration. The skin consists of two layers, an outer *epidermis* and an inner *dermis*. The hairs are derived from the epidermal cells.

Each *hair* develops from cells at the bottom of a tubular ingrowth of the Malpighian layer of the epidermis, known as the *hair-follicle.* The hair is nourished by a vascular papilla, arising from the swollen base of the hair-follicle. The ducts of the *sebaceous glands* open into the hair follicle. They secrete an oily fluid which lubricates the hair. The *sweat-glands* are coiled masses which give off ducts opening at the surface of the

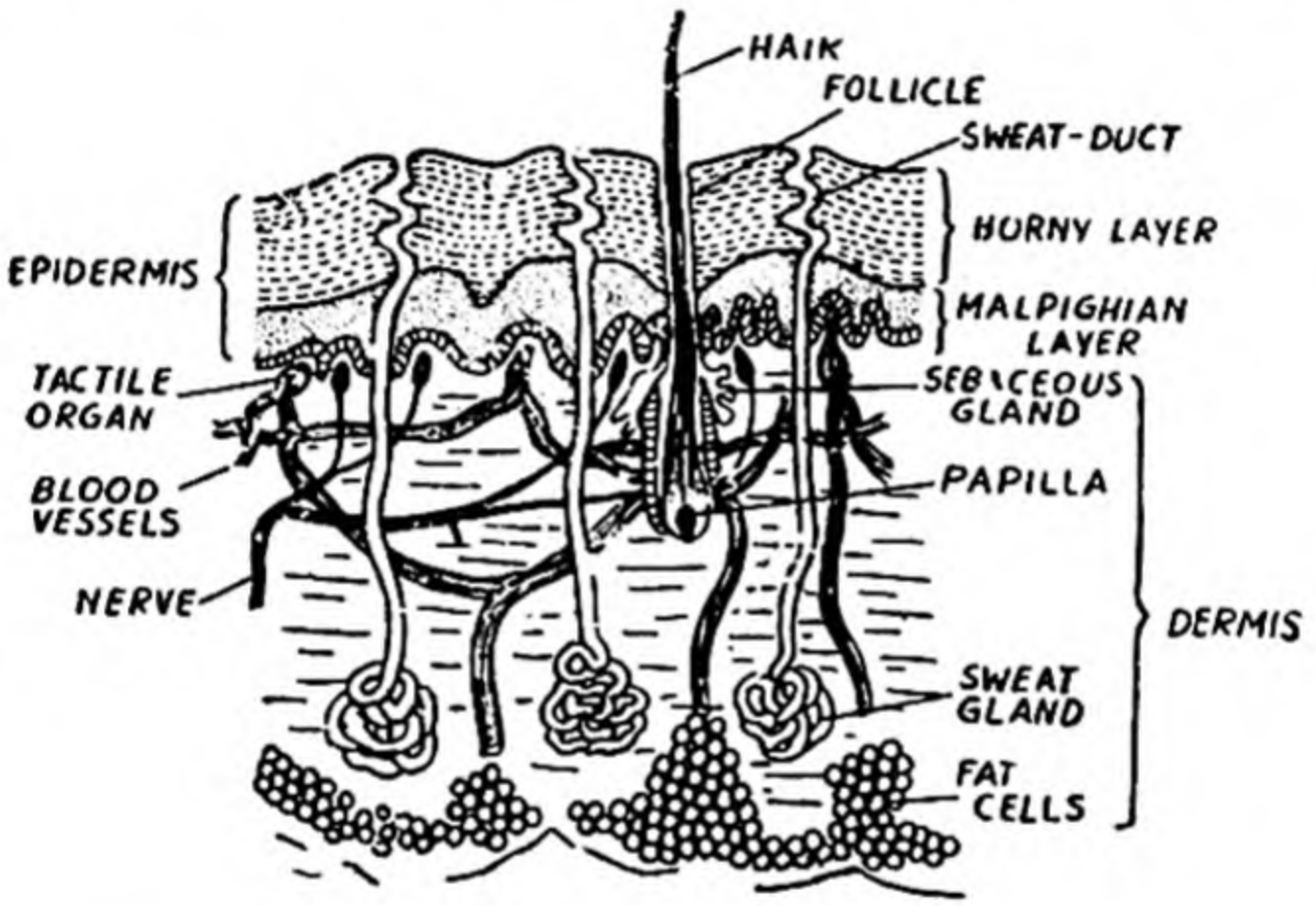


Fig. 138. Mammalian skin, diagrammatic section. (After Wiedersheim).

skin. The sweat is discharged through them. Although situated in the dermis, both the sebaceous glands and the sweat-glands are epidermal in origin.

General Internal Structure. The general arrangement of the internal organs (Fig. 139) is similar to that in the frog. The body-cavity, however, is divided into two parts by a muscular partition, the *diaphragm.* The anterior smaller *thoracic cavity* contains the heart and the lungs while the posterior larger *abdominal cavity* encloses the rest of the organs.

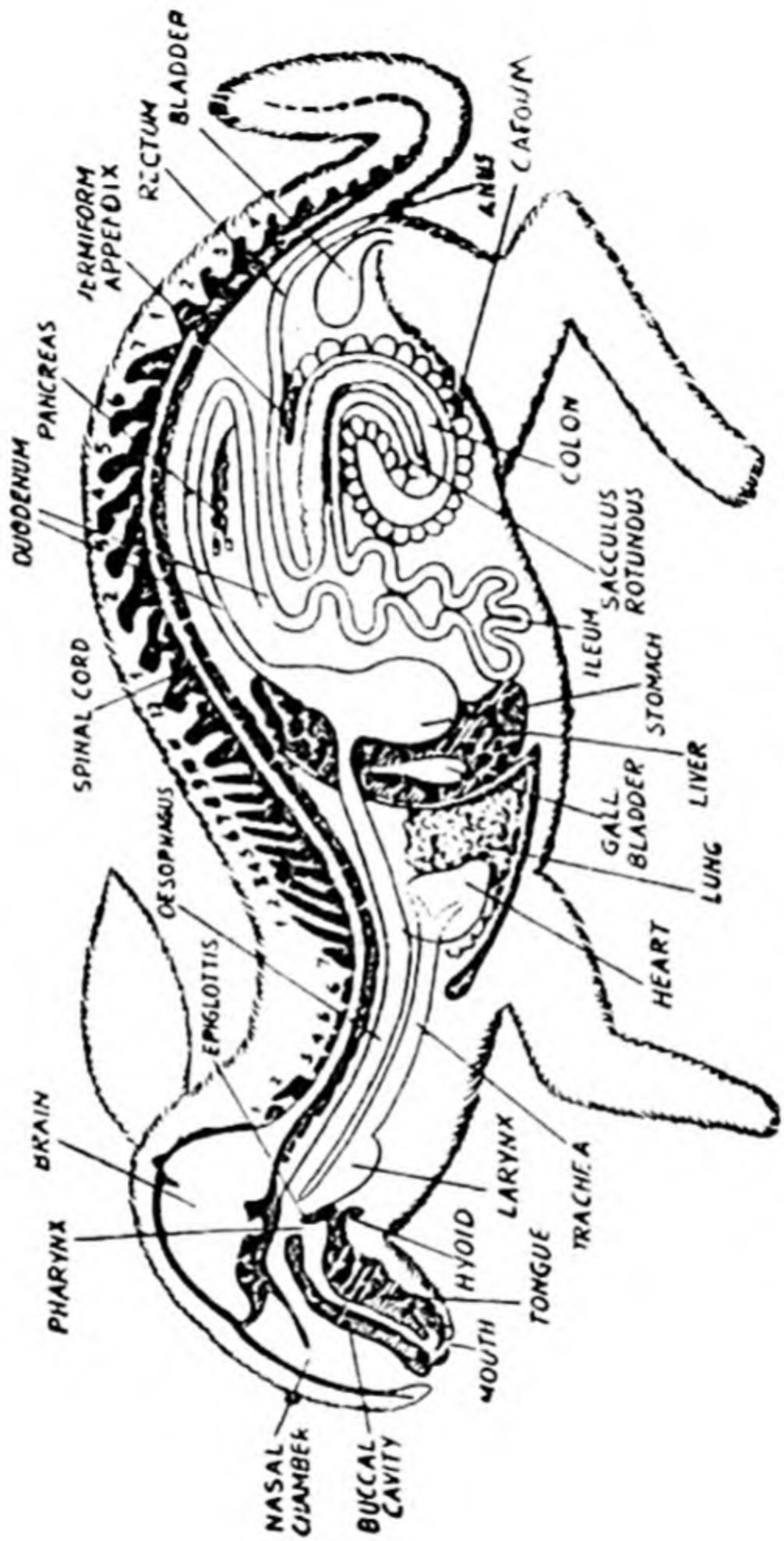


Fig. 139. Internal organs of a rabbit. (From Spratt).

The thorax is further divided into two air-tight *pleural cavities*, each containing a lung. The peritoneum of the thorax is known

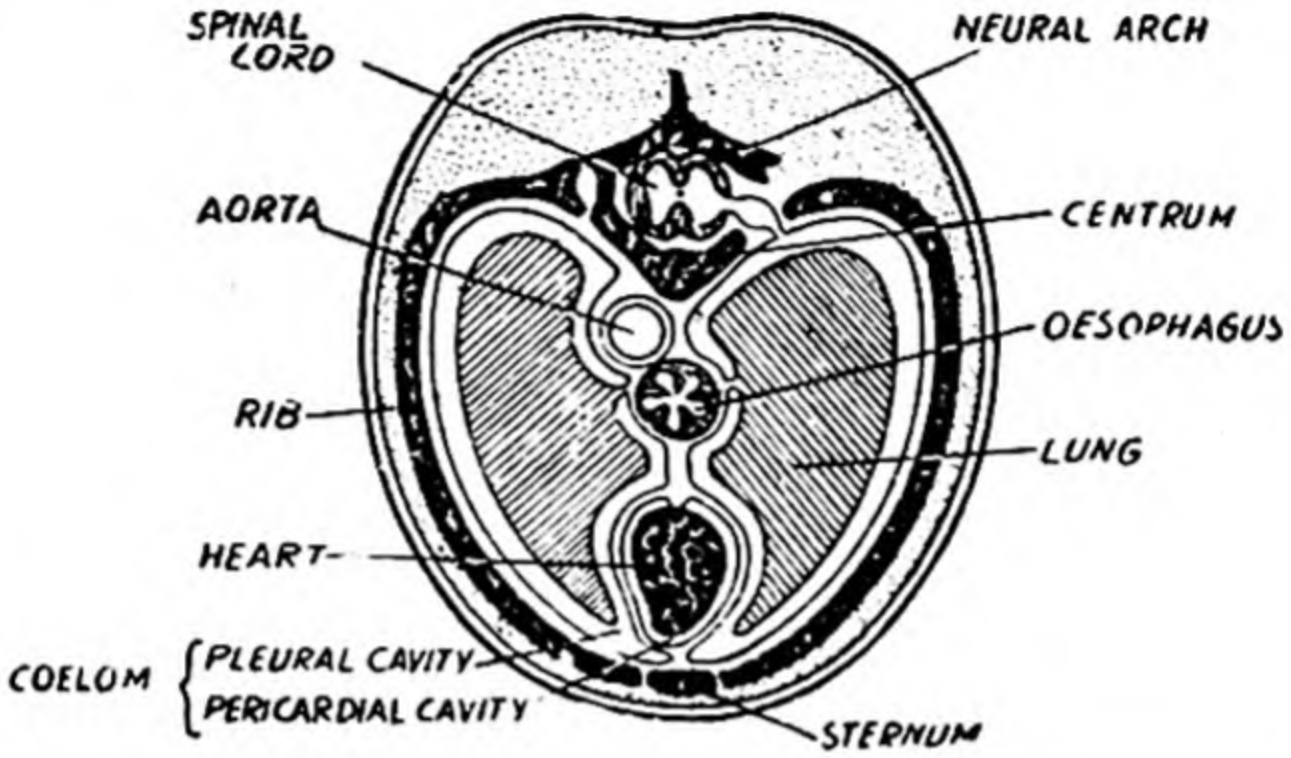


Fig. 140. Transverse section through the thorax of a rabbit.

as the *pleura*. It is made of the *parietal layer* lining the thoracic cavity and the *visceral layer* covering the lungs. The space between the two pleural cavities is known as the *mediastinum*. Its upper part contains the aorta and the oesophagus, and the lower part the heart, enclosed in the pericardium (Fig. 140).

Skeleton. The skeleton of the rabbit consists mostly of bone. The articular surfaces of bones at the joints are covered with cartilage. A few other parts also, to be presently described, are cartilaginous.

Vertebral Column. The *vertebral column* is made up of about forty-five vertebrae. A typical vertebra has the same parts as that of the frog. It consists of a *centrum*, a *neural arch* arising from the centrum and enclosing, the *neural canal*, a *neural spine* above the neural arch, a pair of *transverse processes* and a pair each of *pre-* and *postzygapophyses*. The centra have flat anterior and posterior surfaces, and thus do not form ball

and socket joints with one another, as in the frog. There are, however, *intervertebral discs* of fibro-cartilage interposed between the centra. Another characteristic feature is the presence of two flat discs of bone, the *epiphyses*, fused with the two ends of the centrum. During development the epiphyses arise from centres of ossification which are distinct from that of the main centrum. In skeletons prepared from young rabbits, therefore, the epiphyses become easily detached from the main part of the centrum.

According to their position in the body the vertebrae are divisible into five series, namely, (1) seven *cervical* in the neck, (2) twelve or thirteen *thoracic* in the thorax, (3) six or seven *lumbar* in the abdominal region, (4) three or four *sacral* in the sacral region, and (5) about sixteen *caudal* in the tail (Fig. 141).

The seven *cervical vertebrae* (Fig. 141 C) are characterized by having the transverse processes pierced by paired longitudinal foramina. These together form a *vertebrarterial canal* on either side of the vertebral column in the neck region, and through this canal the vertebral artery, a branch of the subclavian, passes. Another note worthy feature of the cervic al vertebrae is the apparent absence of ribs. But in reality each transverse process represents a short cervical rib fused with the true transverse process. The first cervical vertebra supports the head and is called the *atlas* (Fig. 141 A) after the mythical giant who is believed to have carried the whole world on his shoulder. The atlas is like a ring with very much reduced centrum, broad horizontal transverse processes and an inconspicuous neural spine. The major part of the centrum of the atlas fuses, during development, with the second vertebra to form a conical *odontoid process*, which projects forwards from the centrum of the second vertebra. Anteriorly the atlas bears two large concave facets for articulation with the occipital condyles of the skull, and posteriorly two small facets for articulation with the second vertebra. The articulation between

the skull and the atlas is such that the former can move only in an up and down direction. The second cervical vertebra

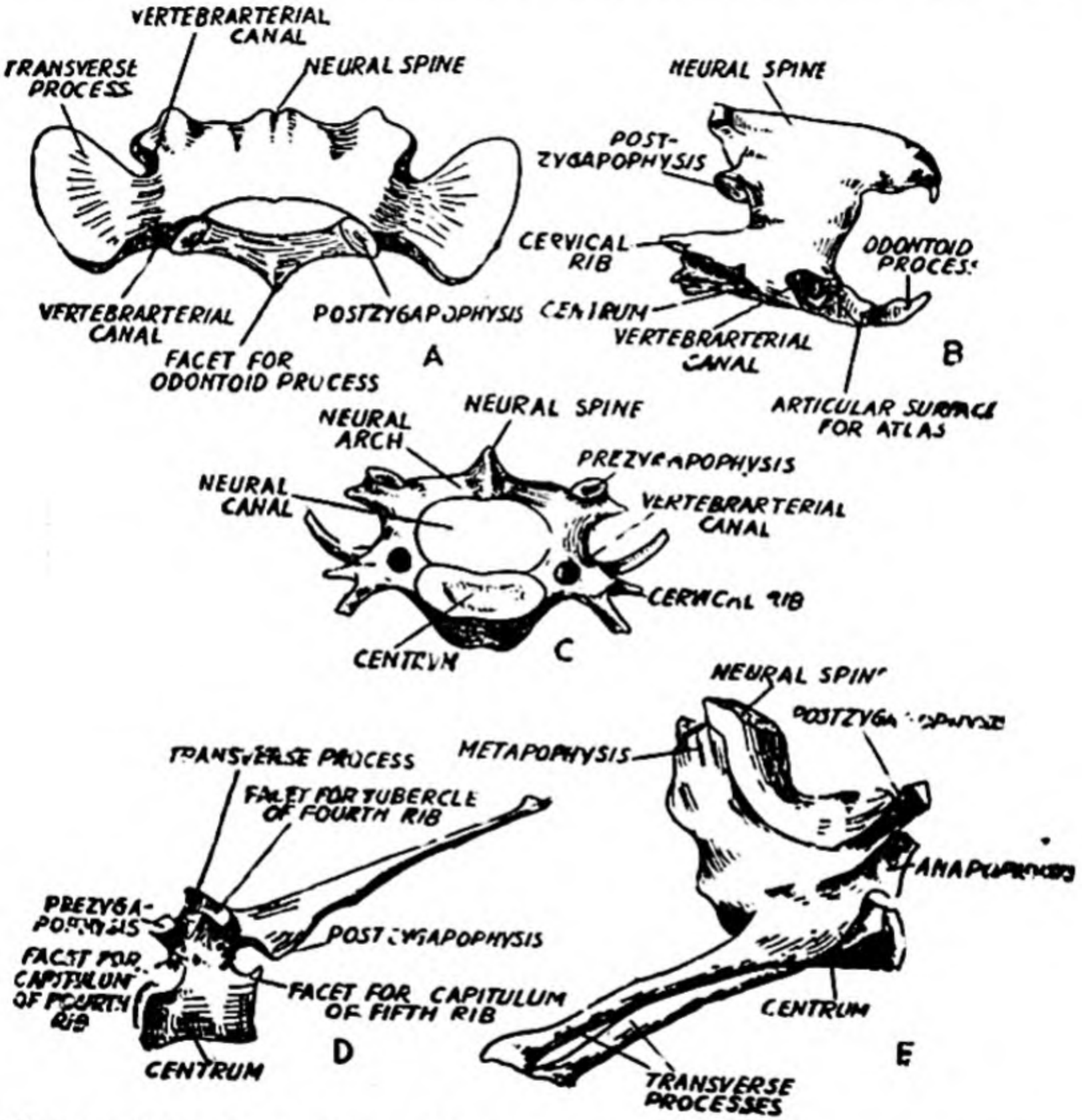


Fig. 141. Selected vertebrae of the rabbit. A, atlas, dorsal view; B, axis, from the right side; C, fifth cervical vertebra, anterior view; D, fourth thoracic vertebra, from the left side; E, third lumbar vertebra, from the left side.

or *axis* (Fig. 141 B) has a strong ridge-like neural spine and small transverse processes. The prezygapophyses are absent.

The odontoid process fits into the ventral portion of the neural canal of the atlas and is held in position by a strong transverse

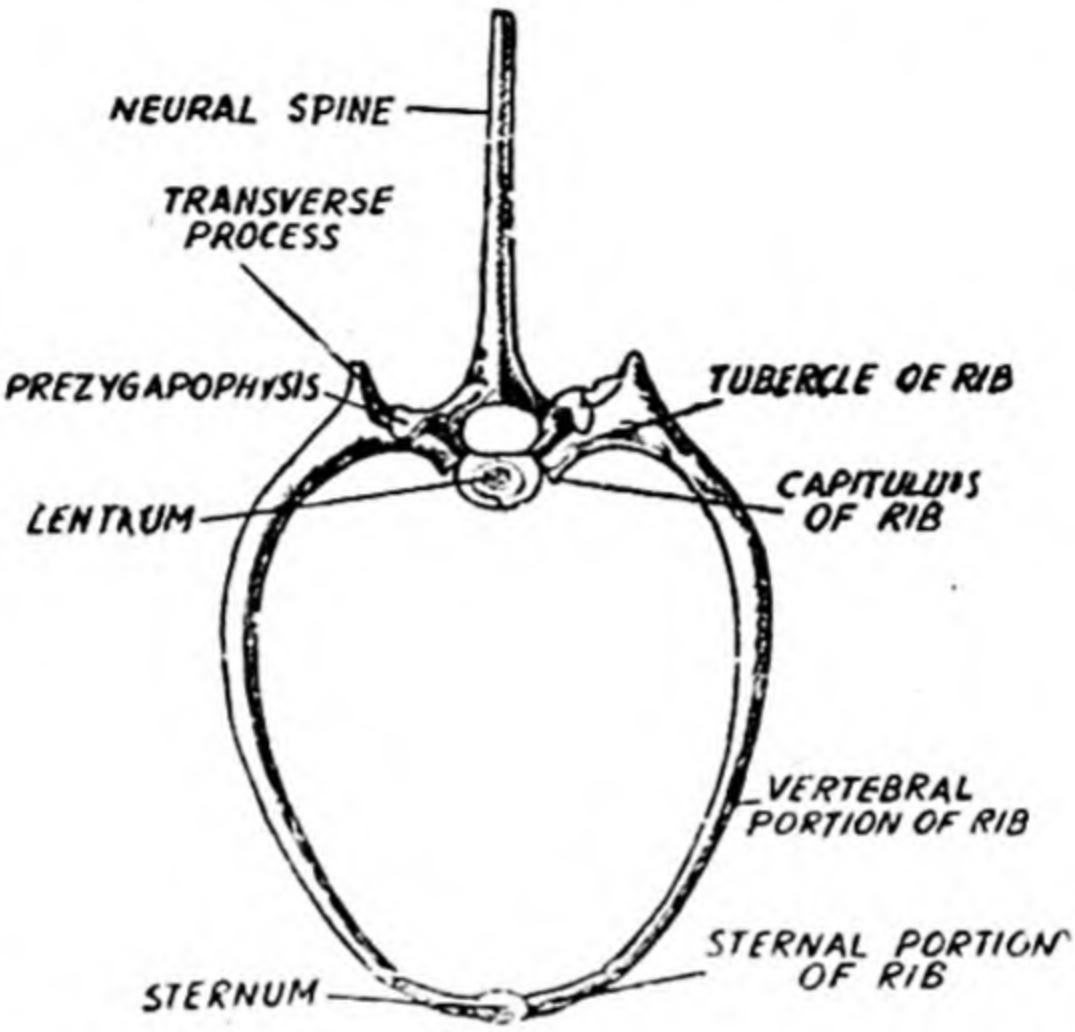


Fig. 142. Fourth thoracic vertebra of the rabbit with fourth pair of ribs.

ligament. The articulation of the axis with the atlas allows only turning movements round the odontoid process. This is why the second vertebra has been named axis. It should, thus, be noted that when the head is moved up and down the skull moves on the atlas, but when turning movements of the head take place the skull and the atlas together move as one unit on the axis. In the remaining cervical vertebrae, except the seventh, the transverse processes are double consisting of dorsal and ventral parts.

Of the twelve or thirteen *thoracic vertebrae* (Fig. 141 D) the first nine have long neural spines pointing backwards, the tenth has a shorter spine projecting upwards and the rest have short spines directed forwards. The ribs, which are forked

dorsally, articulate with the thoracic vertebrae by the forked ends (Fig. 142). The upper limb of each fork articulates with the *tubercular facet* on the lower surface of the transverse process of its side while the lower limb articulates with the *capitular facet* form ed jointly by the anterior edge of the corresponding centrum and the posterior edge of the centrum in front. In the last three or four thoracic vertebrae the tubercular facets are absent and the ribs, which in this region are not forked, articulate with the capitular facets present entirely on the corresponding centra. The posterior four or five vertebrae bear additional processes, above the prezygapophyses, known as *metapophyses*.

The six or seven *lumbar vertebrae* (Fig. 141 E) are larger than the others with well-developed processes. They increase in size from before backwards. Their neural spines are inclined forwards and the large transverse processes are directed outwards, downwards and forwards. In addition to metapophyses above the prezygapophyses, there are slender processes, the *anapophyses*, below the postzygapophyses. In the first two vertebrae a median process, the *hypapophysis*, projects down wards from the ventral surface of the centrum.

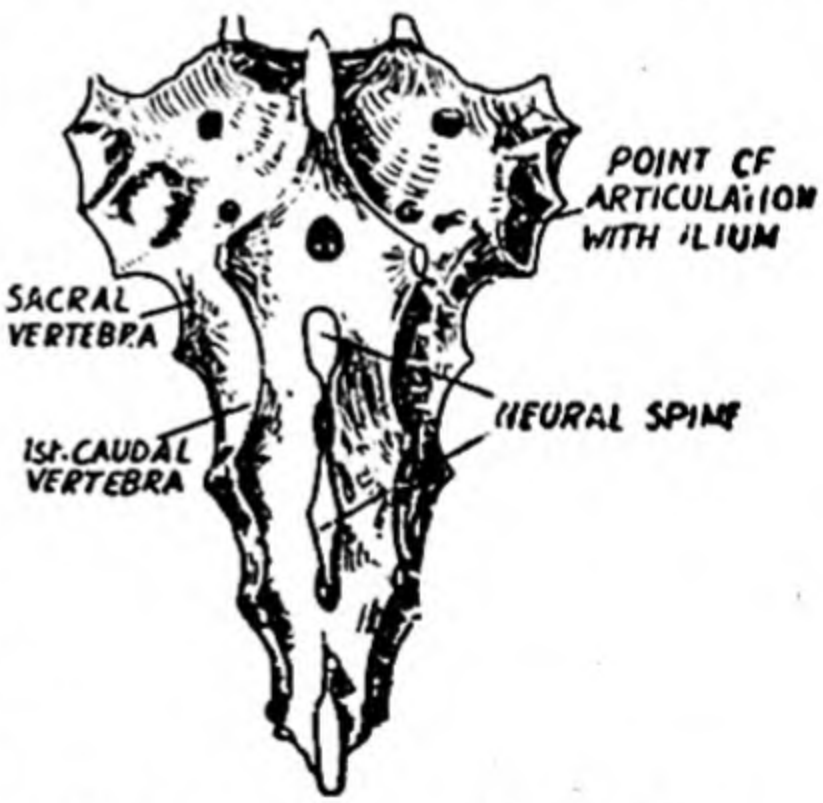


Fig 143. Sacrum of the rabbit dorsal view.

The *sacral vertebrae* are fused to form the *sacrum* (Fig. 143). The transverse processes of the first two vertebrae, particularly those of the first, are greatly expanded and articulate with the pelvic girdle. These two vertebrae, therefore, are the true sacral vertebrae. One or two anterior caudal vertebrae, how-

ever, are fused with them to form a *compound sacrum*, and are designated as sacral.

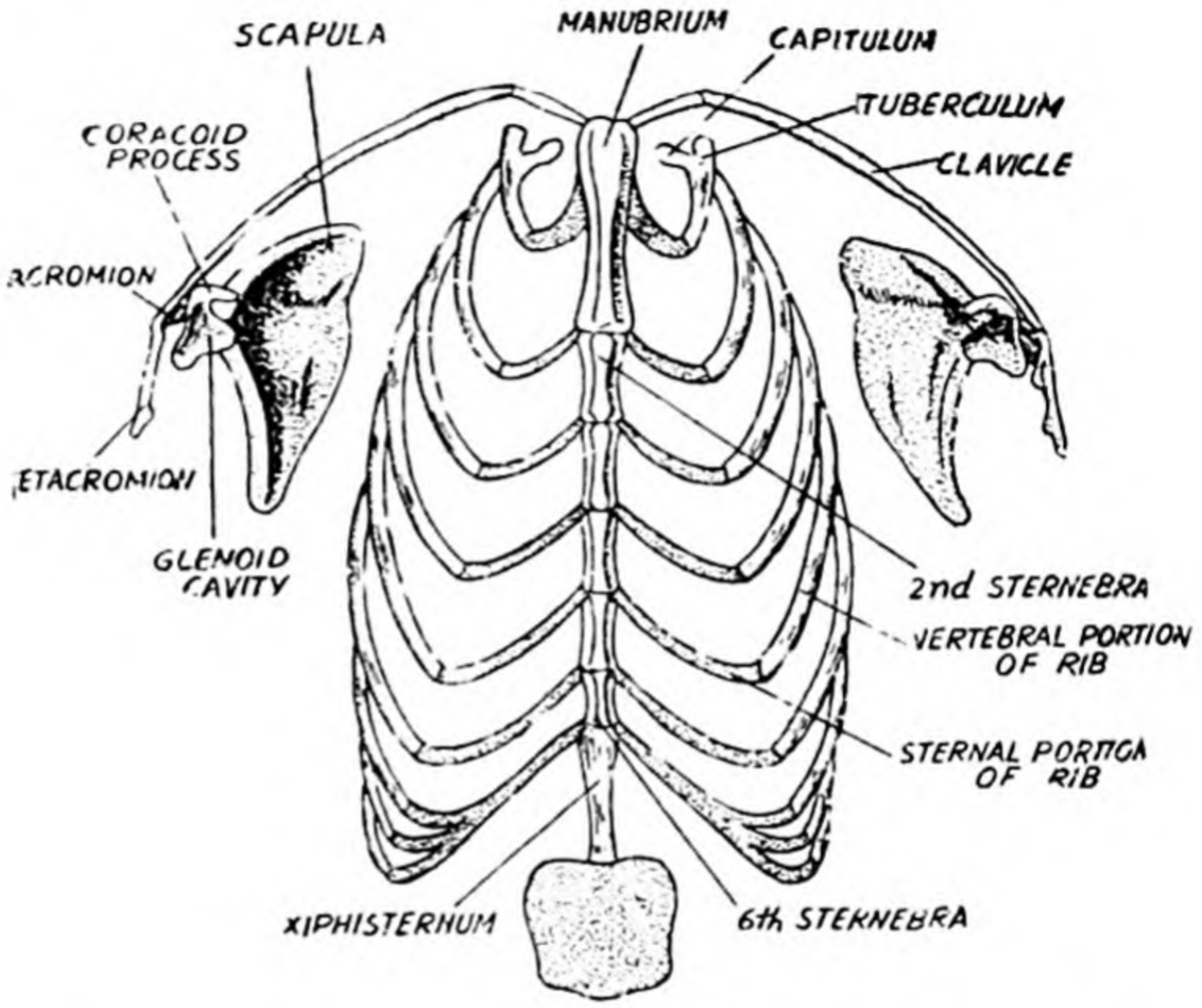


Fig 144. Sternum, ribbs and pectoral girdle of the rabit, ventral view. (After Borradaile).

The *caudal vertebrae*, which are about sixteen in number, gradually diminish in size from before backwards. Towards the posterior end they lose their processes and the neural arches and are represented only by their centra.

Ribs and Sternum. There are twelve or, occasionally, thirteen pairs of ribs (Fig. 144). They are slender curved rods surrounding the thorax. They articulate with the thoracic vertebrae above, and, the first seven pairs, with the sternum

below. Each rib has a dorsal bony *vertebral portion* and a ventral cartilaginous *sternal portion*, which is calcified. The dorsal end of the rib articulates with the capitular facet on the adjoining centra and is known as the *capitulum*. In the first nine pairs of ribs there is close to the capitulum, also a *tuberculum* which articulates with the transverse process. Three types of ribs may be recognised. The first seven pairs which directly articulate with the sternum are the *true ribs*, the eighth. and ninth pairs, which are ventrally attached to the seventh pair, are the *false ribs* and the last three pairs, which are free ventrally, are the *floating ribs*.

The *sternum* (Fig. 144) lies in the mid-ventral line of the thorax. It consists of seven bony segments or *sternebrae*. The first segment or the *manubrium* is the largest followed by four segments of equal size. The sixth segment is the shortest. The seventh or the last segment, the *xiphisternum*, is rather long and bears at its hinder end a broad plate of cartilage, the *xiphoid cartilage*. The first pair of ribs articulates with the sides of the manubrium while the next six pairs between the successive segments.

Skull. The skull of the rabbit (Figs. 144—147) contains a much larger number of bones and is more complicated than that of the frog. Most of the bones are joined with one another by *sutures*, many of which are irregular and wavy. The skull consists of two main regions, a posterior larger *cranial region* and an anterior conical *facial region* forming the skeleton of the snout. The two regions make an angle with each other. The auditory capsules lie in the side walls of the cranial region. On the sides of the skull between the craninum and the facial region are the two large *orbits* separated from each other by a thin vertical *interorbital septum* pierced by a large foramen for the optic nerve, known as the *optic foramen*.

The *cranium* forms a bony box for the protection of the brain, and has a large, opening, the *foramen magnum*, in its

posterior wall through which the brain is continuous with the spinal cord. The bones of the cranium are arranged in

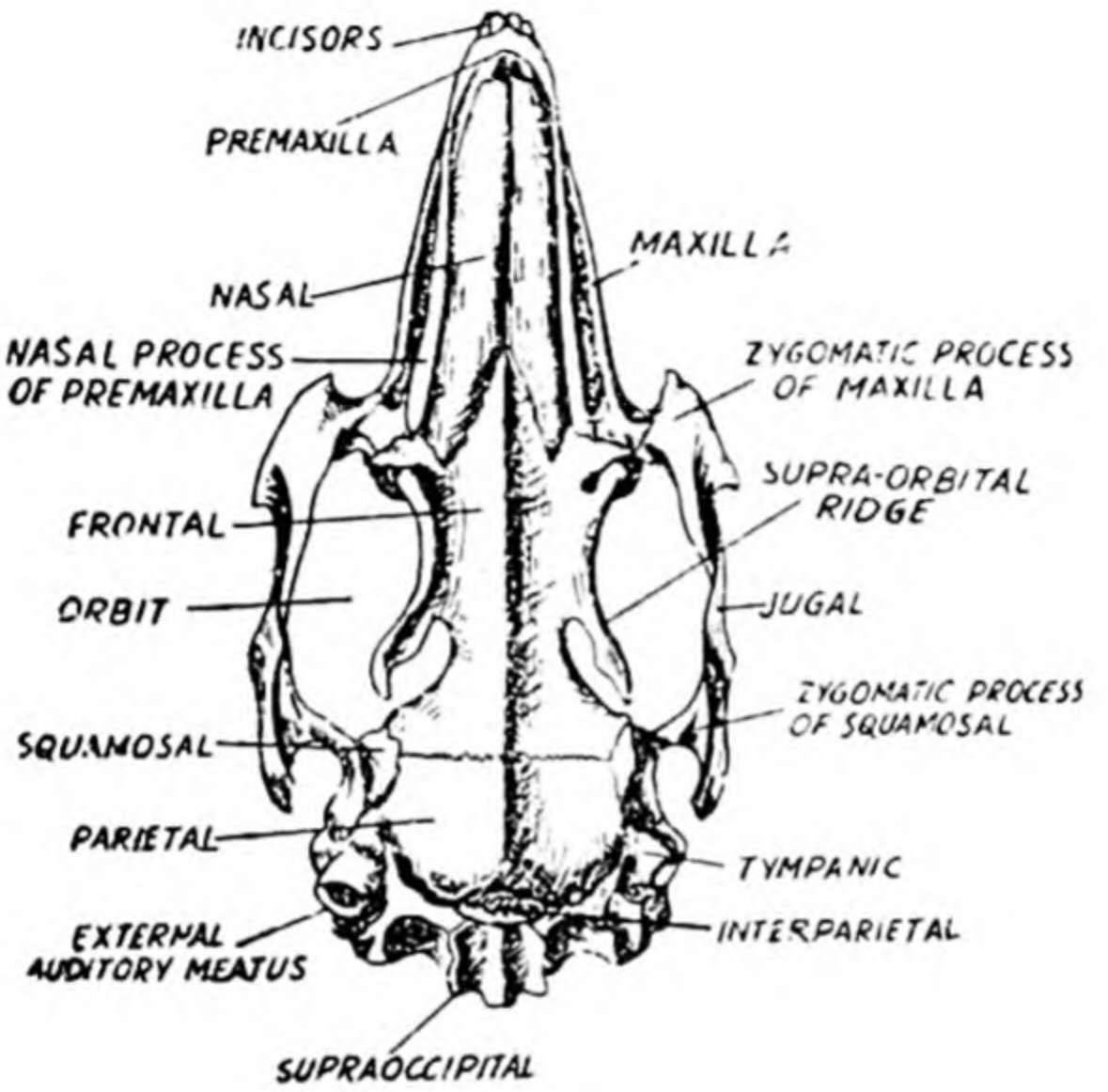


Fig. 145. Dorsal view of the skull of a rabbit.

three segments or rings. The posterior or the *occipital seyment* consists of four cartilage bones surrounding the foramen magnum, namely, the *basioccipital* below, the two *exoccipitals*, one on either side, and the *supraoccipital* above. The last named bone has a shield-shaped projection on the dorsal side. Each exoccipital is produced downwards into a *paroccipital process*. The two *occipital condules* are formed partly by the basioccipital and partly by the exoccipitals. The middle or the *parietal segment* is continuous with the occipital segment except at the sides where it is separated from the latter by the auditory capsule and the squamosal bones. The parietal segment consists

of five bones -- the *basisphenoid* below, two *alisphenoids* at the sides and two *parietals* above. Of these the parietals alone are

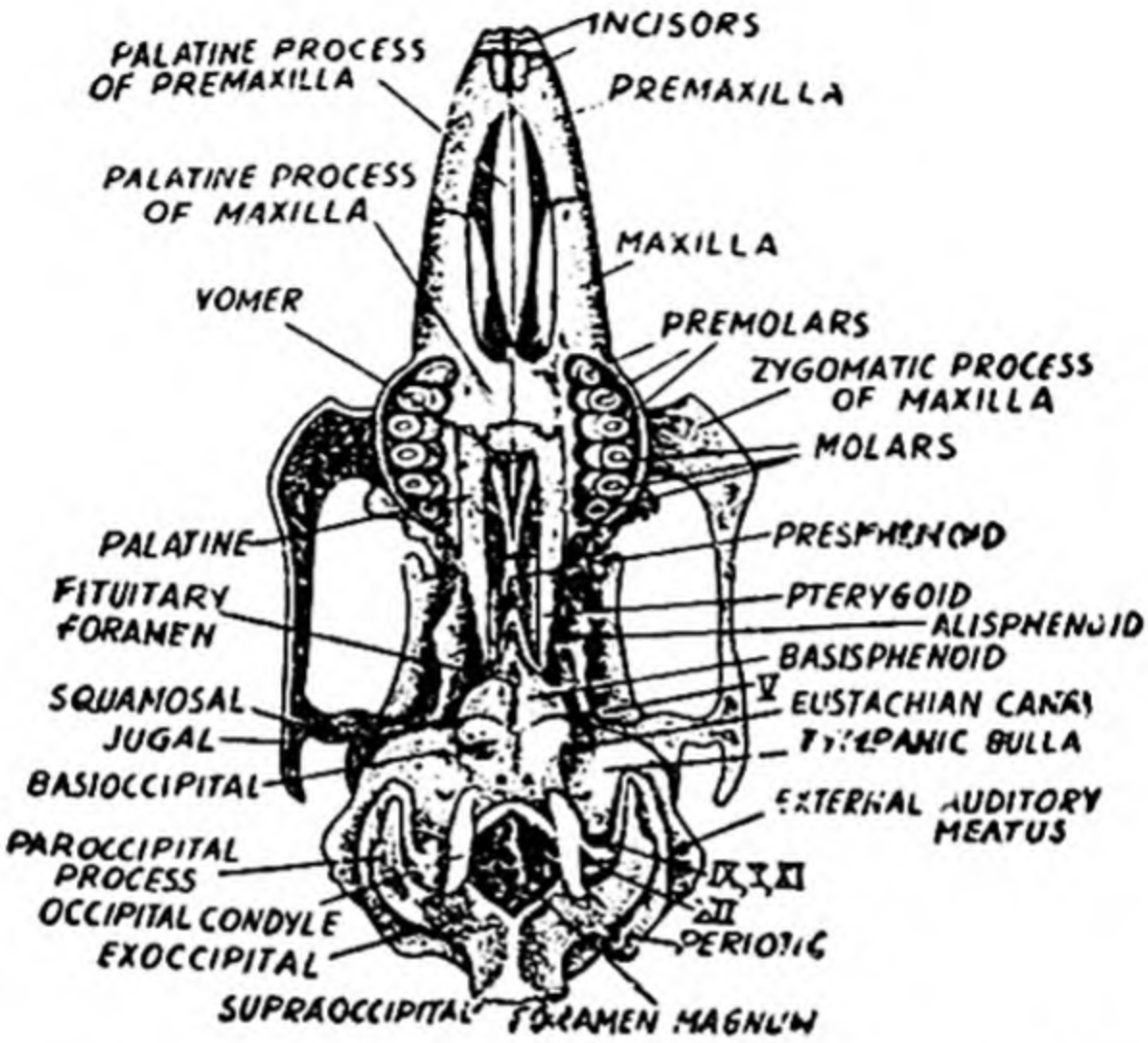


Fig. 146. Ventral view of the skull of a rabbit.

membrane bones, the rest being cartilage bones. The basisphenoid is a triangular bone and forms the floor of the parietal segment. It is connected posteriorly with the basioccipital by a thin plate of cartilage. It is pierced by an aperture, the *pituitary foramen*, and its internal surface has a depression which lodges the pituitary body. The alisphenoids are a pair of thin wing-like bones which are united below with the basisphenoid and separated above from the parietals by the squamosals. Each alisphenoid is produced ventrally into two thin plates which converge and unite with each other anteriorly to form the *pterygoid process*. The parietals are a pair of large thin bones

forming the roof of the parietal segment. The two parietals are united with each other by a suture along the middle line. A small median membrane bone, the *interparietal*, lies between the parietals and the supraoccipital. The anterior or the *frontal segment* also consists of five bones—the *presphenoid* below, two *orbitosphenoids* at the sides and two *frontals* above. All the bones are cartilage bones except the frontals which are membrane bones. The presphenoid is a small bone in front of the basisphenoid with which it is connected by cartilage. It surrounds the optic foramen on the lower and front sides. The orbitosphenoids are completely fused with the presphenoid and surround the remaining part of the optic foramen. The two frontals unite with each other in the mid-dorsal line by a suture and form the roof and the upper part of the sides of the cranium in the orbital region. Each frontal bears a prominent process, the *supraorbital ridge* The front wall of the cranium is formed by a vertical cartilage bone, the *cribriform plate*, perforated by numerous apertures for the passage of the branches of the olfactory nerves.

The *auditory capsules* lie on the sides of the cranium between the occipital and the parietal segments. Each capsule consists of a large bone, the *periotic*, formed by the fusion of three cartilage bones which are distinct in the embryo. The inner *petrous portion* of this bone is dense and hard, and encloses the membranous labyrinth of the ear, while the outer *mastoid portion* is porous and is visible externally. A flask-shaped bone, the *tympanic*, is closely applied to the outer surface of each periotic. The body of the flask, known as the *tympanic bulla*, encloses the tympanic cavity into which opens the Eustachian tube. The neck of the flask forms the external auditory canal, at the base of which stretches the tympanic membrane and whose mouth forms the auditory opening. The inner wall of the tympanic bulla is incomplete and the tympanic cavity in

this region is closed by the outer wall of the petrous portion of the periotic. When the tympanic is removed two small apertures are seen on the outer wall of the periotic bounding the tympanic cavity. The anterior of these is the *fenestra ovalis* and the posterior the *fenestra rotunda*. A chain of three small cartilage bones, the *malleus*, *incus* and *stapes*, which will be fully described in connection with the organ of hearing, stretches across the tympanic cavity from the tympanic membrane to the fenestra ovalis. These three bones are known as *auditory* or *ear ossicles*.

The *olfactory capsules* lie in front of the cranium. The two capsules are roofed by a pair of long membrane bones, the *nasals* which unite by sutures with the frontals behind and with each other in the middle line. The sides and the floor of the capsules are formed by the premaxillae, maxillae and the palatines which are bones of the upper jaw. The two nasal cavities are separated from each other by a vertical plate of cartilage, the *mesethmoid*, which is united behind with the cribriform plate. In the median line below the mesethmoid is a pair of slender membrane bones, the *vomers*, which are fused together and bear a groove on their upper surface. The lower edge of the mesethmoid fits into this groove. Posteriorly the vomers form a horizontal partition separating the nasal cavities from a narial passage leading to the throat. Three pairs of thin, much folded membrane bones, the *turbinals*, project from the walls into the nasal cavities and thereby increase their internal surface. According to the bones with which the turbinals are united. the latter are known as the *ethmo-turbinals*, *naso-turbinals* and *maxillo-turbinals*.

In the anterior corner of each orbit there is a loosely fitting membrane bone, the *lacrymal*, which is often missing in the dried skull.

As in the frog, the *upper jaw* consists of a number of paired membrane bones. The *premaxillae* form the anterior part of

the facial region and bear sockets for the cutting teeth (incisors). Each premaxilla sends backwards a long *nasal process*

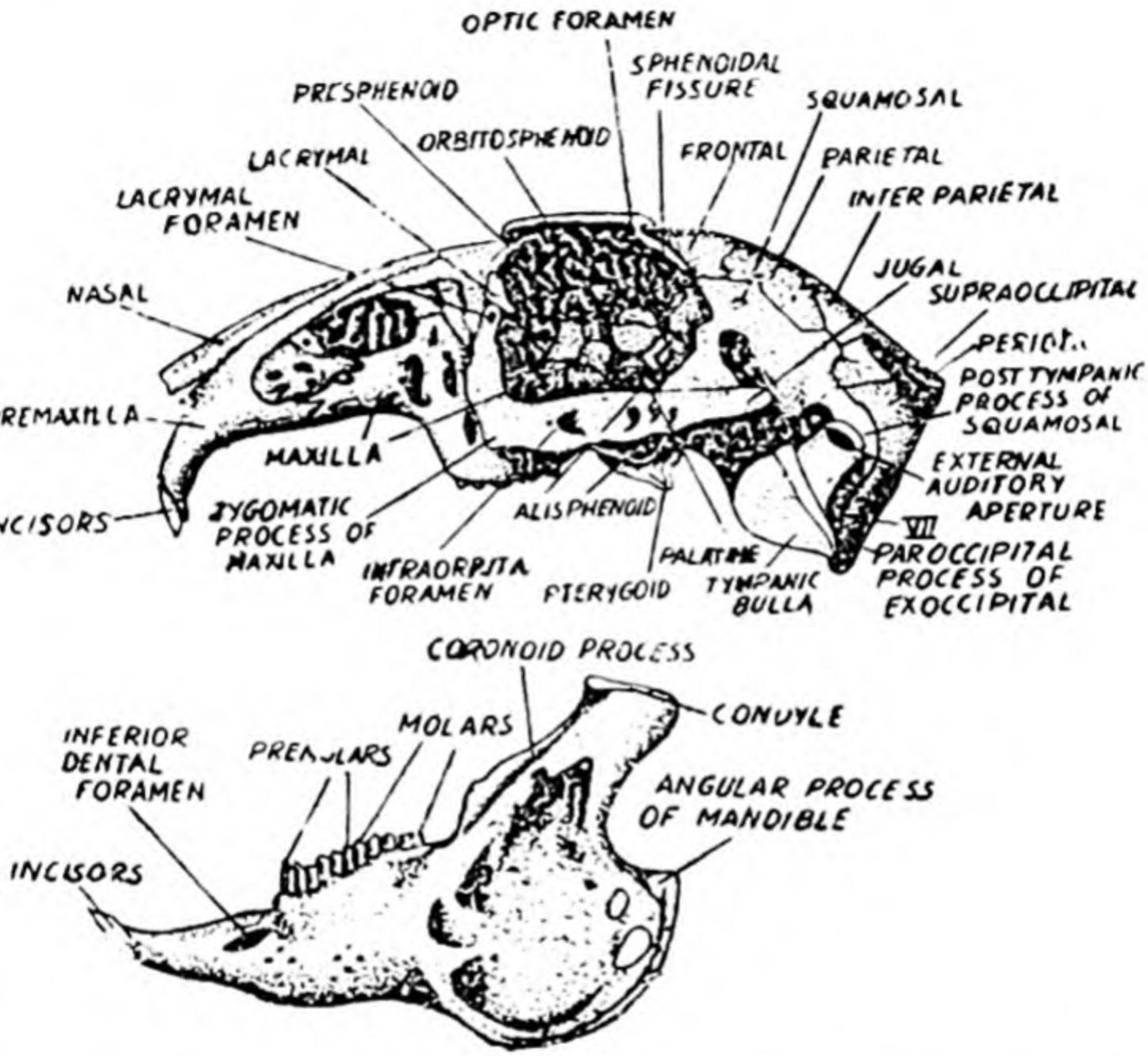


Fig. 147. Lateral view of the skull of a rabbit with lower jaw.

which is wedged in between the nasal and the maxilla and united posteriorly with the frontal. It also gives off on the ventral side a *palatine process* which, along with its fellow of the other side, forms the front part of the hard palate. The *maxillae* are large irregular bones which lie behind the premaxillae. They are partly fenestrated on the sides and bear sockets for the grinding teeth (premolars and molars). From the outer side of each maxilla arises a *zygomatic process* which

forms the anterior part of the *zygomatic arch*. The latter runs from the cranium to the facial region bounding the orbit ventro-laterally. Each maxilla gives off from its inner side a horizontal *palatine process* which, with its fellow from the other side, forms the middle part of the hard palate. The *palatines* are thin plates of bone placed more or less vertically behind the maxillae. They are attached to the presphenoid above, and the pterygoids and orbitosphenoids behind. The anterior end of each palatine gives off ventrally a horizontal process which, meeting its counter part from the opposite side, forms the posterior part of the hard palate. The *pterygoids* are narrow vertical bones attached to the base of the cranium at the junction of the basisphenoid and the alisphenoids. The *squamosals* lie on the sides of the cranium in front of the periotics. They are attached to the parietals, frontals, orbitosphenoids and alisphenoids. From the posterior border of each squamosal arises a small process which overlaps the periotic. Another more prominent curved *zygomatic process* arises from its outer side, bearing on its under surface a facet for the articulation of the lower jaw. The *jugals* are flat bars of bone each lying between the zygomatic processes of the maxilla and the squamosal of its side, thus completing the zygomatic arch. It should be noted that the quadrate bone is absent in the rabbit.

The *lower jaw* (Fig. 147) is made up of two halves or *rami*. Each ramus consists of a single membrane bone, the *dentary*. The two rami are united with each other in front but diverge posteriorly. Each ramus bears a condyle at the posterior end of the upper margin for articulation with the skull. In front of the condyle is a ridge-like *coronoid process*. The postero-ventral border of each ramus forms the *angular process*. The socket for the single incisor is at the anterior end and further back, in front of the coronoid process, are the sockets for the premolars and molars.

The *hyoid* (Fig. 148) which lies at the root of the tongue and to which the tongue muscles are attached, is a remnant of the visceral skeleton, which in fishes supports the gills. It consists of a plate of bone, the *body* or *basihyal*, a pair of short *anterior horns* or *cornua* and a pair of longer *posterior horns* or *thyrohyals*.

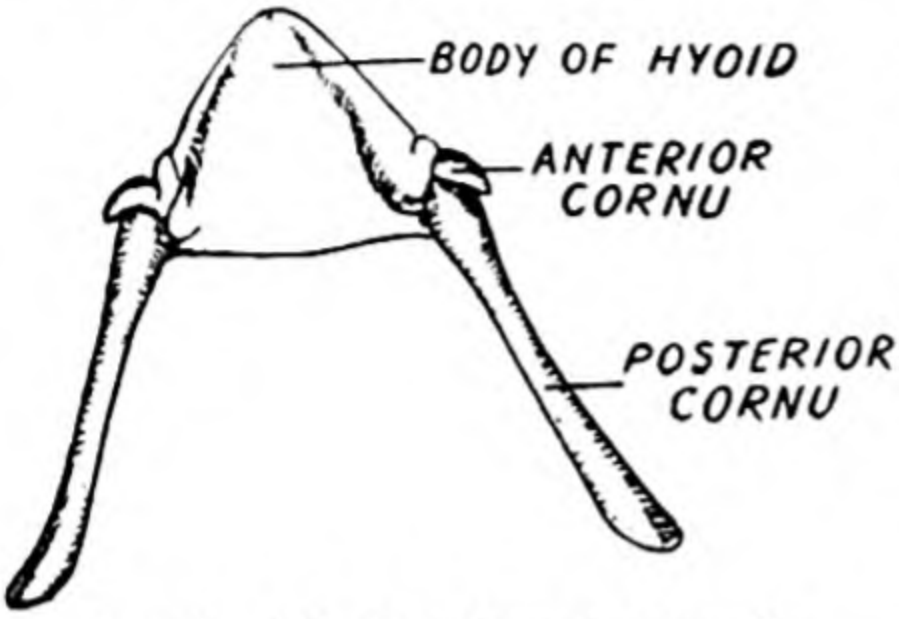


Fig. 148. The hyoid apparatus of a rabbit.

Pectoral Girdle. Due to the presence of ribs in the thoracic region, the *pectoral girdle* does not form a complete arch, as in the frog, but the two halves remain separate, each of which consists mainly of a single flat triangular bone, the *scapula* (Fig. 149). Its apex, which is directed downwards and forwards bears the *glenoid cavity* for articulation with the humerus, while its base consists of a strip of cartilage, the *supra-scapula*. On its outer surface is a longitudinal ridge or *spine* whose lower free end is known as the *acromion* which gives off backwards a process, the *metacromion*. The coracoid, which fuses with the scapula early in development is represented by a small *coracoid process* overhanging the glenoid cavity. The *clavicle* (Fig. 144) is a slender curved membrane bone attached by ligament at its outer end to the acromion process of the scapula and at its inner end to the sternum.

Fore-limb. The bones of the fore-limb resemble closely those of the frog. The *humerus* (Fig. 150 A) bears at its proximal end a rounded *head* for articulation with the glenoid cavity to form the shoulder-joint. The head is continuous in

front with a shallow groove for the insertion of the tendon of the biceps muscle. On the sides of the groove are two tuberositics and below the head is the *delloid ridge*, for the attachment of muscles. The distal end of the humerus is shaped into a pulley-like *trochlea*, for articulation with the bones of the fore-arm. Just above the trochlea on the posterior side is a cup-shaped depression, the *olccranon fossa*, for receiving the olecranon process of the ulna. The fossa is pierced by an aperture, the *supratrochlear foramen*. The *radius* (Fig. 150 B) lies on the inner side of the fore-arm and is shorter than the ulna Its proximal extremity bears a double articu ar surface for the trochlea of the humerus and its distal end two shallow concavities for the carpal bones. The *ulna* (Fig. 150 B) extends beyond the radius to form the *olecranon process* and below it is a deep *sigmoid notch* for articulation with the trochlea. The distal end of the ulna articulates with the carpus. The *carpus* (Fig. 151) consists of two rows of carpal bones. The proximal row contains three bones, namely, the *radiale* and *intermedium* articulating with the radius, and the *ulnare* articulating with the ulna. The distal row contains five bones of which the middle one is the *centrale* and the remaining four, strictly speaking, make up the distal row of

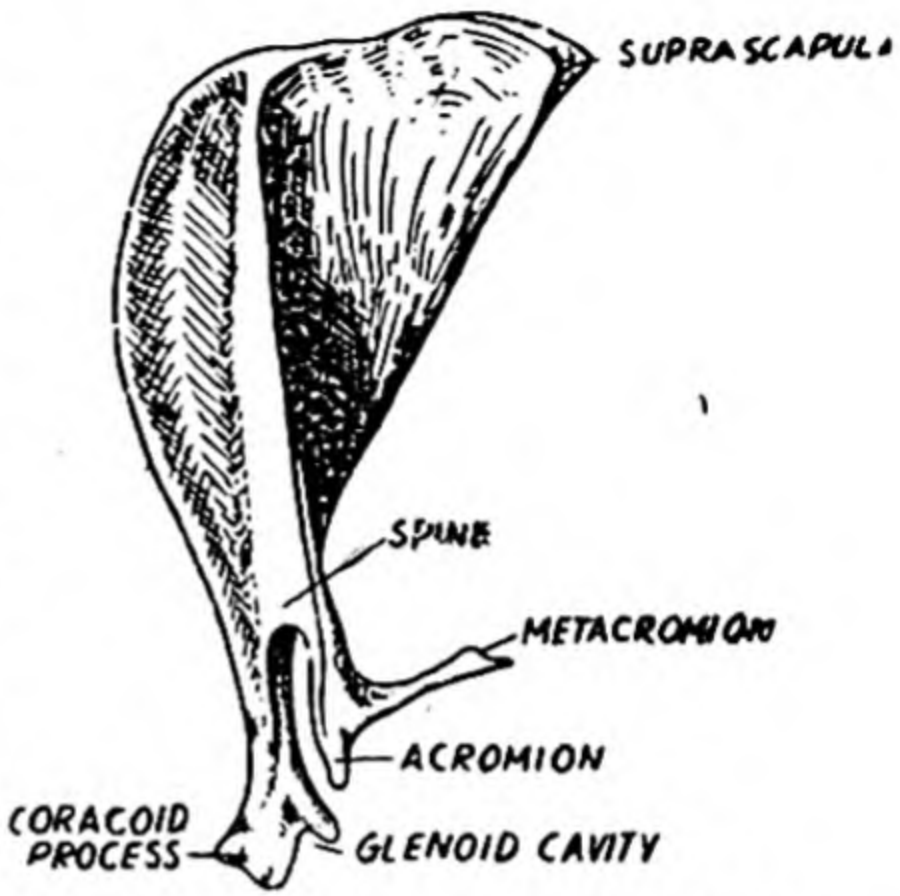


Fig. 149. Left scapula of a rabbit, viewed from the outer side.

carpals. Of these the first three articulate with the corresponding digits, and the fourth, which in reality consists of the

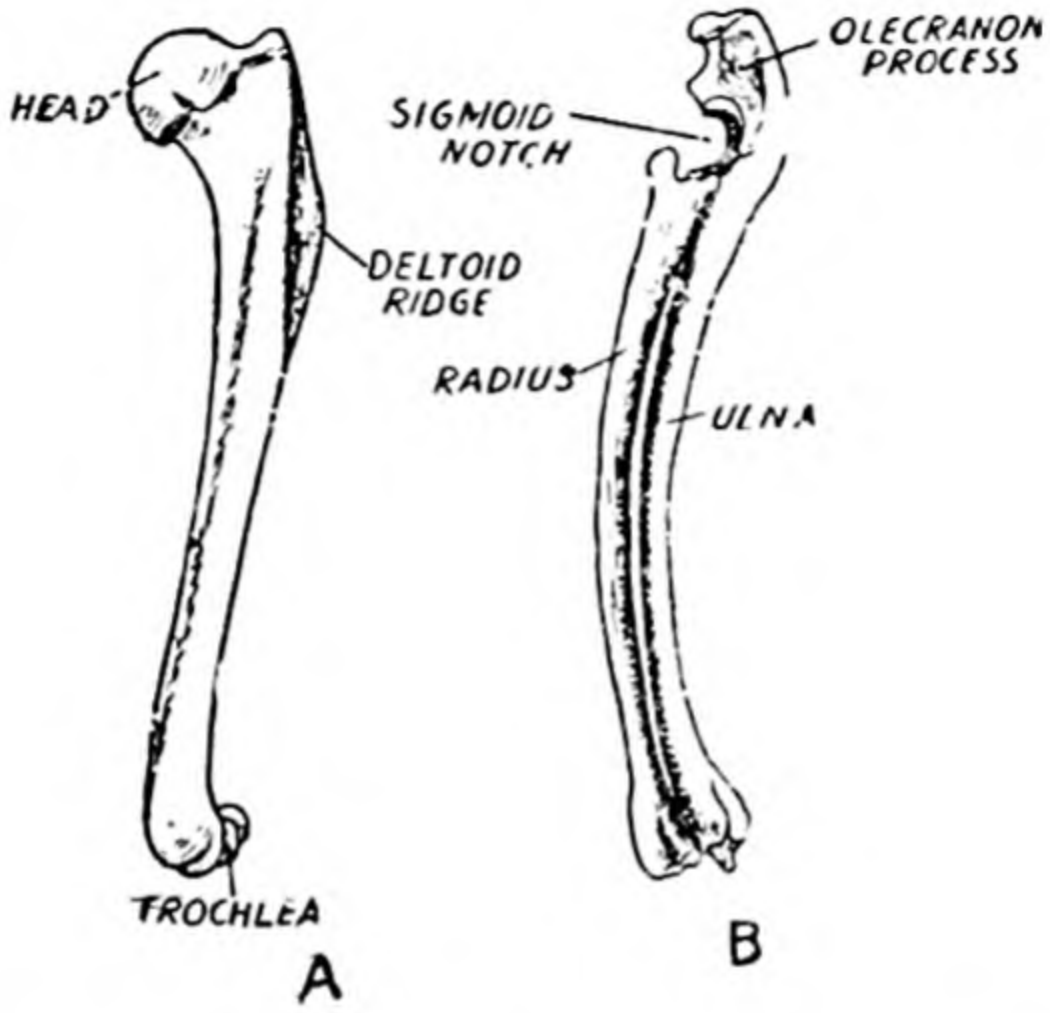


Fig. 150. A, left humerus of a rabbit, front view ; B, left radius and ulna of a rabbit, side view.

fourth and fifth carpals fused together, articulates with the fourth and fifth digits. A small *pisiform* bone is present on the posterior side of the carpus. There are five *metacarpals*. The thumb, which is the shortest digit, has two *phalanges* and the other digits three phalanges each. The terminal phalanx of each digit bears a horny *claw*.

In the rabbit the bones of the fore-limb are permanently fixed in a position known as *pronation* in which the palm of the hand faces downwards and the thumb points inwards. In this position the radius and the ulna cross each other. In the case of man the fore-arm can be rotated from the position of pronation so that the palm faces upwards and the thumb is

turned outwards. This position is known as *supination*. In this, the radius lies parallel and external to the ulna.

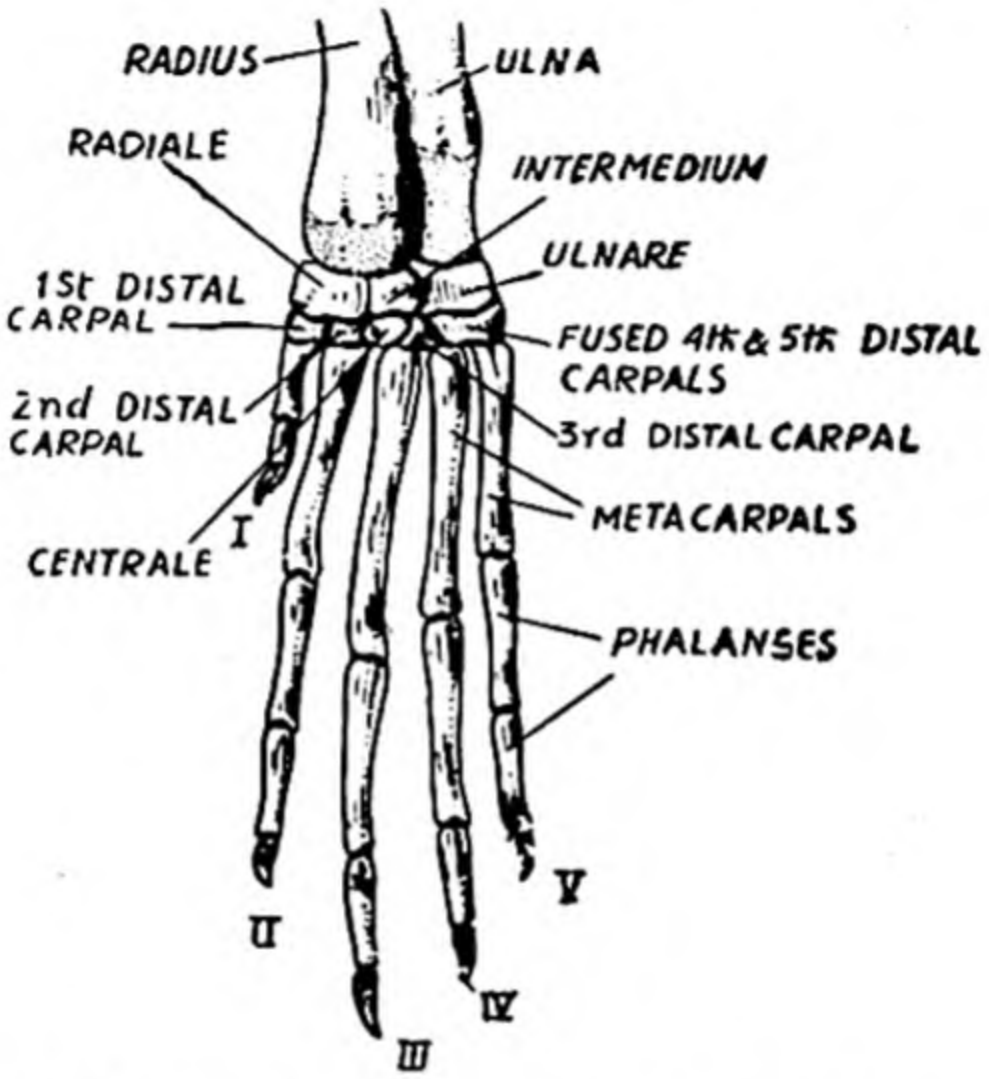


Fig. 151. Skeleton of the left fore foot of a rabbit.

Pelvic Girdle. The *pelvic girdle* (Fig. 152) consists of two halves which unite in the mid-ventral line to form an inverted arch. This arch, with the sacrum, forms a complete ring known as the *pelvis*. Interposed between the two halves, along the line of union, is a persistent strip of cartilage which constitutes a symphysis, known as the *pubic symphysis*. Each half of the girdle or *innominate bone* is pierced by a large aperture, the *obturator foramen*. As this aperture is filled up in life by a connective tissue membrane, it would be more correct to call it the obturator fenestra which bears a small aperture for the obturator nerve. Each half of the girdle consists of three bones, namely, (1) the *ilium*, which is antero-dorsal and articulates

with the sacrum, (2) the *ischium*, which lies above and behind the obturator foramen, and (3) the *pubis*, which lies below and in front of the obturator foramen. About the middle of the outer surface of each half of the girdle is a deep cup-shaped cavity, the *acetabulum*, for articulation with the head of the femur. All the three bones of the girdle on either side take part in the formation of the acetabulum. The boundaries of the bones, however, become obliterated in the adult.

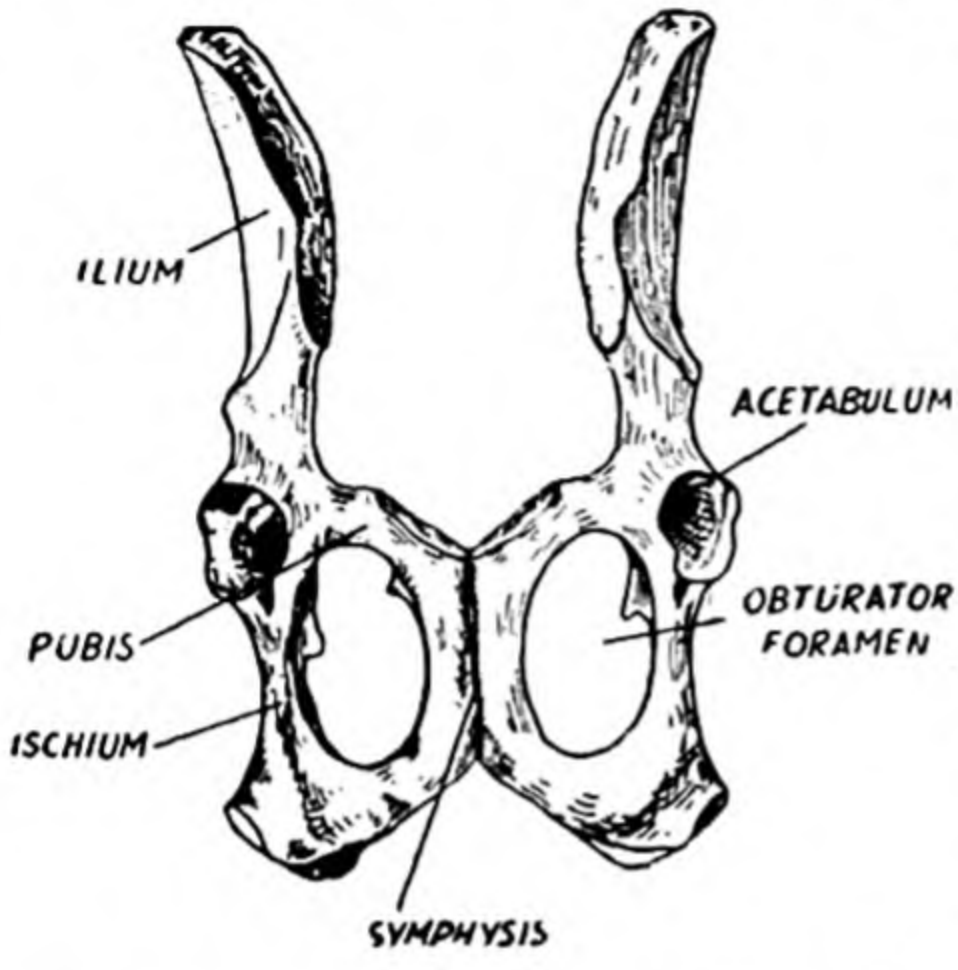


Fig. 152. Ventral view of the pelvic girdle of a rabbit.

Hind-limb. The skeleton of the hind-limb has the same general plan as in the frog. The *femur* (Fig. 153 A) bears near the proximal end, on the inner side, a prominent rounded *head* which fits into the acetabulum to form the hip-joint. The end itself bears a stout-process, the *great trochanter*, while just below the head is the *lesser trochanter*, and opposite this, on the outer side is the *third trochanter*. The three trochanters provide points for the attachment of muscles. The distal end of the femur bears two condyles for articulation with the tibia. Between the two condyles is a deep *intercondylar groove* which is continuous with the *patellar groove* on the front side of the bone. A large sesamoid bone, the knee-cap or *patella*, which is developed in the tendon of the extensor muscle of the leg, slides in the patellar groove and is attached to the tibia by ligament.

There are two small sesamoid bones on the opposite side of the knee-joint. The *tibia* (Fig. 153 B) is the inner bone of the shank.

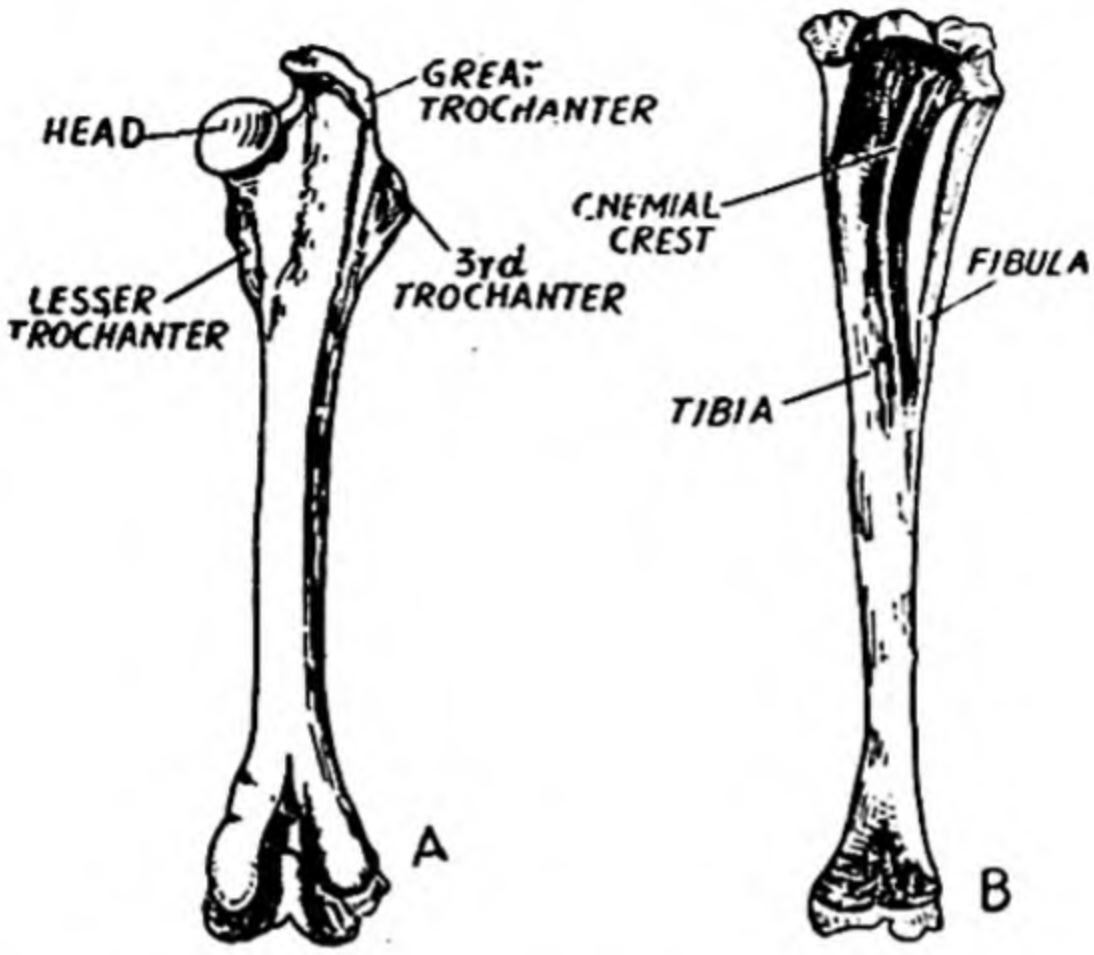


Fig. 153. A, left femur of a rabbit, front view ; B, left tibia and fibula of a rabbit, front view.

It is straight and stout, and the largest of all the limb-bones. It bears at its proximal end two concave facets for the condyles of the femur. A prominent ridge, the *cnemial crest*, is present near the proximal end on the anterior surface. Distally the tibia articulates with the tarsus. The *fibula* (Fig. 153 B) is the outer slender bone of the shank. Its proximal end is attached to the femur but its distal-half becomes completely fused with that bone. The *tarsus* (Fig. 154) consists of two rows of tarsal bones with the *centrale* between them. The proximal row contains two bones, an inner *astragalus*, formed by the fusion of the *tibiale* and *intermedium*, and an outer *calcaneum* or *fibulare*. The astragalus articulates with the tibia by a pulley-like surface while the calcaneum is produced backwards into a strong heel or *calcaneal process*. The

distal row of tarsals consists of three bones. The first tarsal corresponding to the missing hallux, is absent, and the fourth

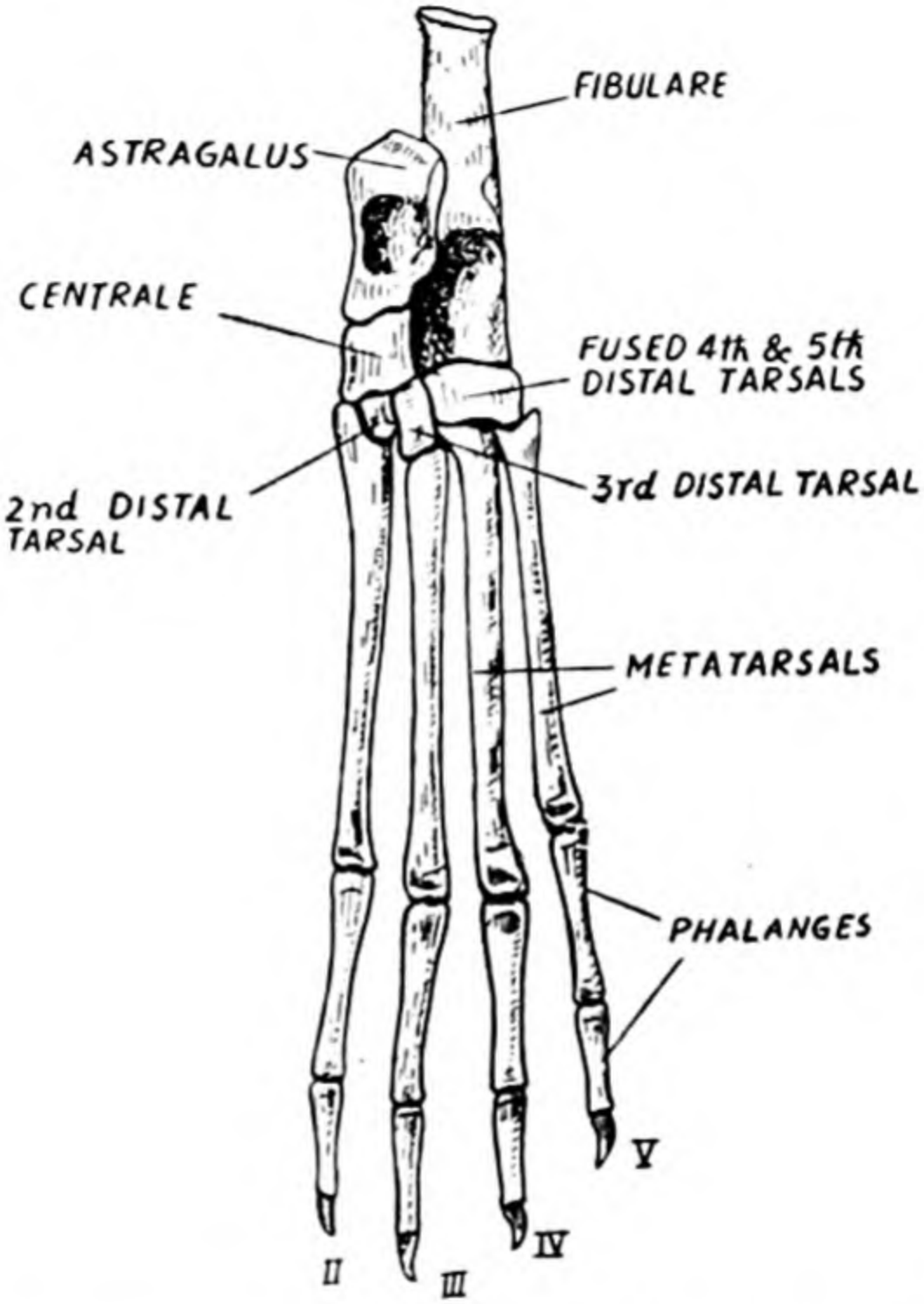


Fig. 154. Skeleton of the left hind-foot of a rabbit.

and fifth tarsals are fused together. There are four *metatarsals*, followed by *phalanges* of which there are three to each digit. The terminal phalanges are clawed. As already noted, the first digit is absent. Small sesamoid bones are present on the ventral surface of the foot.

Digestive System. The *mouth* of the rabbit is relatively small and is bounded by movable lips. The large mouth-cavity is roofed by the *palate*, the anterior part of which, being supported by bone, is known as the *hard palate* and the posterior part, being fleshy, is known as the *soft palate*. The narial passage lies above the palate and the internal nostrils, thus, open into the pharynx and not in the front part of the oral cavity, as in the frog. From the hinder end of the soft palate hangs down a small flap, the *velum palati*, on either side of which is a *tonsil*, resembling in structure a lymphatic gland. The *tongue*, which is highly muscular, is attached to the floor of the mouth-cavity, its anterior end being free. The surface of the tongue in certain places, particularly on the tip, bears papillae containing taste-buds.

The teeth differ in many respects from those of the frog, namely, (1) they are present on both jaws, (2) they are not all alike but differentiated into distinct types, (3) they do not arise as processes of the jaw-bones but are embedded in sockets, and (4) there are two sets of teeth, the milk-teeth and the permanent teeth. The milk-teeth are shed and replaced by the permanent teeth early in life. In the frog the teeth are continuously renewed throughout life. In the rabbit the teeth are differentiated into *incisors*, *premolars* and *molars*. The *canines*, found in most other mammals, are absent. The incisors are present in front and are the cutting teeth while the premolars and molars are situated further back and are the grinding teeth. The molars have no milk predecessors. Between the front teeth and the grinders is a wide gap, the *diastema*. In the upper jaw there are two pairs of incisors, lying one behind the other. The front pair is long, curved and chisel-shaped with sharp cutting edges. The posterior pair is much smaller. There are six pairs of grinders of which the first three are premolars and the last three molars. They have broad surfaces for grinding. In the lower jaw there is a single pair of incisors, two

pairs of premolars and three pairs of molars. The dentition of a mammal is conveniently expressed by a *dental formula*, which in the case of the rabbit is $i\ \frac{2}{1}$, $c\ \frac{0}{0}$, $pm\ \frac{3}{2}$, $m\ \frac{3}{3}=28$. In this formula the incisors, canines, premolars and molars are represented by their initial letters *i*, *c*, *pm* and *m* respectively. The figure above the line indicates the number of teeth in one half of the upper jaw while that below the line the number of teeth in one half of the lower jaw. As the teeth of the right and the left halves are equal in number, the total number of teeth in both jaws can be determined by doubling the total number shown in the formula. The dental formula of man is $i\ \frac{2}{2}$, $c\ \frac{1}{1}$, $pm\ \frac{2}{2}$, $m\ \frac{3}{3}=32$.

Each tooth (Fig. 155) is mainly composed of *dentine* which is covered, in the exposed part of the tooth, by *enamel*, and in the part embedded in the socket by *cement*. The enamel is derived from the epidermis lining the mouth-cavity while the two other constituents from the dermis. The tooth is hollow containing a *pulp-cavity* filled with connective tissue, blood vessels and nerves. It has an opening at the base. In the rabbit the aperture of the pulp-cavity remains wide open enabling the tooth to continuously grow at the base throughout life. Such teeth are known as *rootless* or are said to have persistent pulps. In many other mammals, including man, the opening of the pulp-cavity is wide during the growing period but becomes narrow when the tooth is fully formed, after which no further growth takes place.

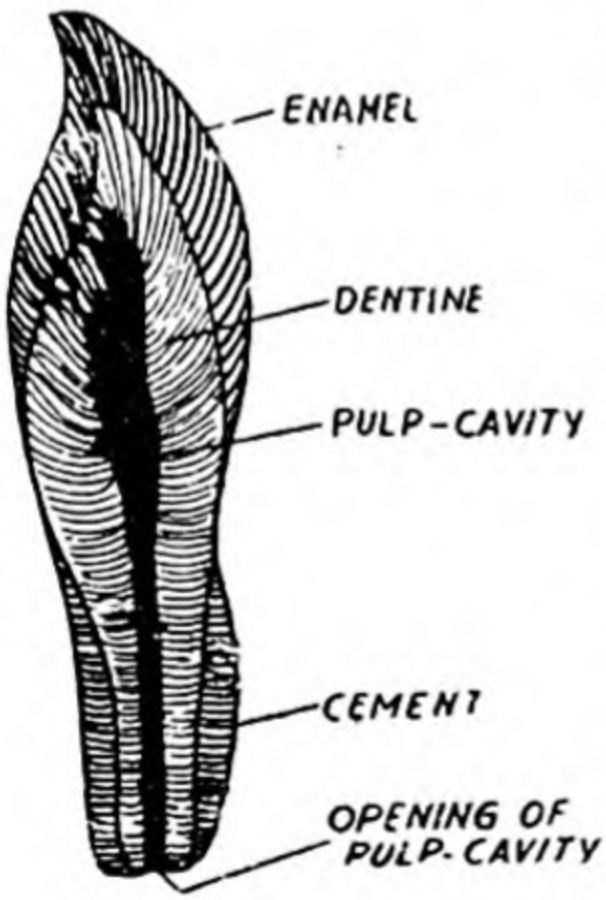


Fig. 155. Longitudinal section of a mammalian tooth. (After Wiedersheim).

During the process of mastication the food is thoroughly mixed with the *saliva* which is secreted by four pairs of *salivary glands*. These are : (1) the *infra-orbitals* in the cheeks below the eye-balls, (2) the *parotids* beneath the ears, (3) the *submaxillaries* between the angles of the lower jaw in the middle line, and (4) the *sublinguals* below the tongue. The saliva contains a ferment called *ptyalin* which converts starch into sugar. Digestion of food, thus, starts in the mouth in contrast to that in the frog where it is swallowed unchanged. The mouth-cavity is continuous behind with the pharynx (Fig. 139) which leads posteriorly into the oesophagus above and the larynx below. The opening of the larynx or the *glottis* is guarded by an elastic flap of cartilage covered with mucous membrane and known as the *epiglott.s* which is present only in the mammals. The epiglottis projects upwards from the front edge of the glottis. When the food is swallowed the epiglottis is pressed back over the glottis which is thus closed. In this manner the food is prevented from going into the trachea. Into the pharynx also open the Eustachian tubes and the narial passage. The posterior part of the latter is known as the *naso-pharynx*.

The *oesophagus* is a long narrow tube which runs backwards through the neck and the thorax, and piercing the diaphragm, enters the abdomen, where it opens into the stomach. The *stomach* (Fig. 156) is an ovoid sac lying transversely in the abdomen. It is divided into a wide *cardiac portion* on the left side and a narrower pyloric portion on the right side. The latter opens into the *duodenum*, which is the first part of the small intestine, by a small aperture, the *pylorus*, bounded by a sphincter muscle. The duodenum runs back along the left side of the abdomen, and then turning forwards forms a U-shaped loop. The rest of the small intestine, called the *ileum*, is seven to eight feet long and forms a series of complicated coils. It ends in a rounded sac, the *sacculus rotundus*. The internal surface of the ileum bears numerous minute processes, the *villi*,

which considerably increase the absorptive surface. The large intestine consists of a wide sacculated *colon* and a narrow

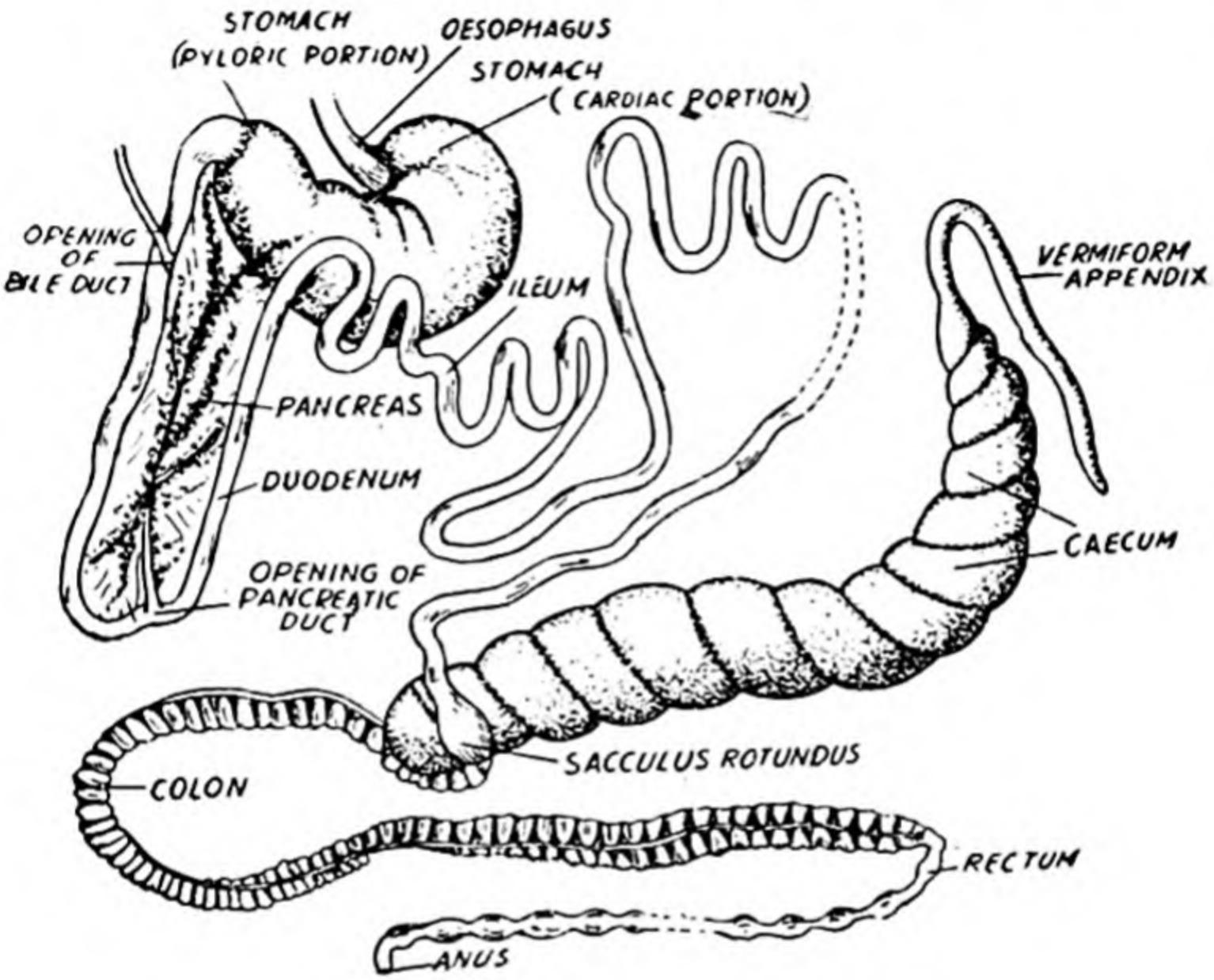


Fig. 156. The alimentary canal of a rabbit.

rectum, the latter having a beaded appearance due to faecal pellets inside it. The rectum opens to the exterior at the *anus*. At the junction of the ileum and colon is a wide dark-coloured tube, the *caecum*, the outer surface of which is spirally constricted. It ends blindly in a finger-like *vermiform appendix*. The caecum is particularly well-developed in herbivorous mammals. Its function is to digest the cellulose which is brought about by the action of bacteria living inside it. As in the frog, the intestines are suspended from the body-wall by folds of the *mesentery*.

The *pancreas* (Fig. 156) is a much branched gland lying in the mesentery connecting the two limbs of the duodenum. The pancreatic duct opens independently of the bile-duct into the distal limb of the duodenum a little distance from the bend. The *liver* is dark red in colour and consists of five lobes. It is attached to the diaphragm by a fold of the mesentery. The green, thin-walled *gall-bladder* lies in a depression on the posterior surface of the second lobe from the right. Several small *hepatic ducts* arise from the various lobes of the liver and unite to form the bile-duct, which after receiving a *cystic duct* from the gall-bladder runs backwards as the *common bile-duct* to open into the duodenum near the pylorus.

Endocrine Glands. The endocrine glands are more or less similar to those of the frog but also differ in certain respects. The *spleen* is a dark and crescent-shaped body lying in the mesentery attached to the dorsal side of the cardiac end of the stomach. The *thymus* lies below the pericardium. The *thyroid* consists of two lobes lying one on either side of the larynx connected by a bridge of glandular tissue across the ventral side of the thyroid cartilage. In the *adrenals* the irregular groups of cells, found in the frog, have been concentrated to form two compact rounded bodies. Regarding the functions of the endocrine glands the only additions necessary here pertain to the *pituitary body* which lies, as in the frog, on the ventral surface of the brain behind the optic chiasma. One of the hormones produced by this gland stimulates the muscles of the uterine wall causing them to vigorously contract. It is believed to assist in the expulsion of the embryo after it is fully developed. The pituitary also stimulates the activity of the mammary glands.

Respiratory System. The respiratory organs (Fig. 139) as well as the mechanism of respiration differ considerably from those in the frog. The external nares lead into a long narial

passage which is separated from the oral cavity by the palate and which opens behind into the pharynx. Due to the presence of a neck, the larynx and the trachea, which in the frog are combined to form the laryngo-tracheal chamber, are separated from each other. The larynx opens anteriorly, through the *glottis*, into the pharynx and posteriorly into the trachea. As already noted, the glottis is guarded by an elastic flap, the *epiglottis*. The *trachea* is a long tube running in the neck ventral to the oesophagus. Its walls are supported by rings of cartilage which are incomplete on the dorsal side. These rings prevent the trachea from collapsing. In the thorax the trachea divides into two branches or *bronchi*, each bronchus going into the corresponding lung. The cartilaginous rings are continued into the bronchi but gradually disappear towards their distal ends. The *lungs* are pair of spongy organs which lie in the thoracic cavity enclosed in pleural membranes which are attached to the dorsal wall of the thorax. The thoracic cavity is bounded by the walls of the thorax on all sides except the posterior where it is partitioned from the abdominal cavity by the *diaphragm*. Each bronchus, on entering the lung, breaks up into a large number of *bronchioles* which end in minute *air-sacs* or *alveoli* in whose thin walls lie the pulmonary capillaries. It is in the air sacs that the exchange of oxygen and carbon dioxide takes place.

The mechanism of respiration is radically different from that in the frog. Whereas in the frog the air is forced into the lungs by raising the floor of the buccal cavity, in the rabbit the air is sucked into the lungs by the expansion of the thoracic cavity. By the action of the intercostal muscles the ribs are pulled outwards, at the same time the diaphragm, which projects convexly towards the thorax, when the latter is unexpanded, becomes flattened. The result of these two changes is that the thoracic cavity is enlarged and a partial vacuum is created inside it. The lungs expand to fill up the vacuum causing in turn a partial

vacuum in themselves which is filled with air from the exterior. This part of respiration is known as *inspiration*. The move-

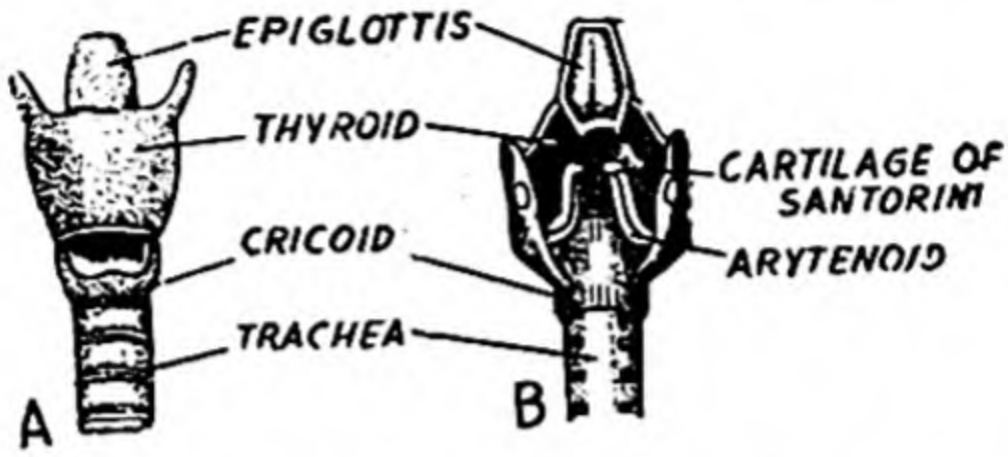


Fig. 157. Larynx of the rabbit. A, ventral view ; B, dorsal view. (After Schneider)

ments are now reversed. The walls of the thorax contract as a result of the relaxation of the intercostal muscles, and the diaphragm again becomes convex by the action of its own muscles. The decrease in the volume of the thoracic cavity, thus produced, increases the pressure on the lungs and expels the air. This part of respiration is known as *expiration*.

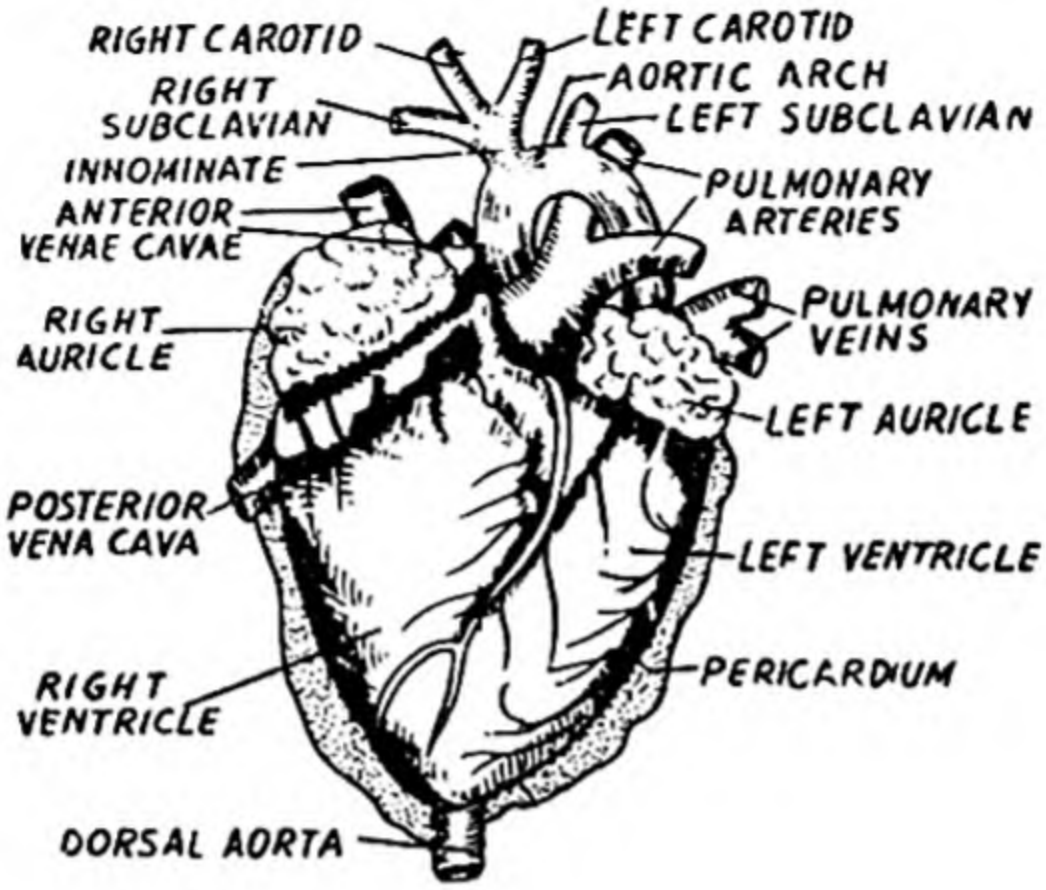
The *larynx* or *voice box* (Fig. 157) lies at the anterior end of the trachea of which it is a modified part. The wall of the larynx is supported by a number of cartilages, namely, (1) the *thyroid*, which is a broad semi-circular place of cartilage lying ventrally, (2) the paired *arytenoids* which are small in size and lie dorsally and (3) the *cricoid* which is ring-shaped and is situated posteriorly. Its dorsal part is much broader than the ventral. A pair of small nodules, the *cartilages of Santorini* is attached to the anterior ends of the arytenoids. The *vocal cords* are two elastic folds which stretch across the larynx dorso-ventrally from the arytenoids to the thyroid. When not in use the vocal cords lie at an acute angle to each other but at the time of the production of sound they become parallel to each other by the action of the laryngeal muscles. Sound is

produced by the vibration of the cords brought about by the respiratory current of air..

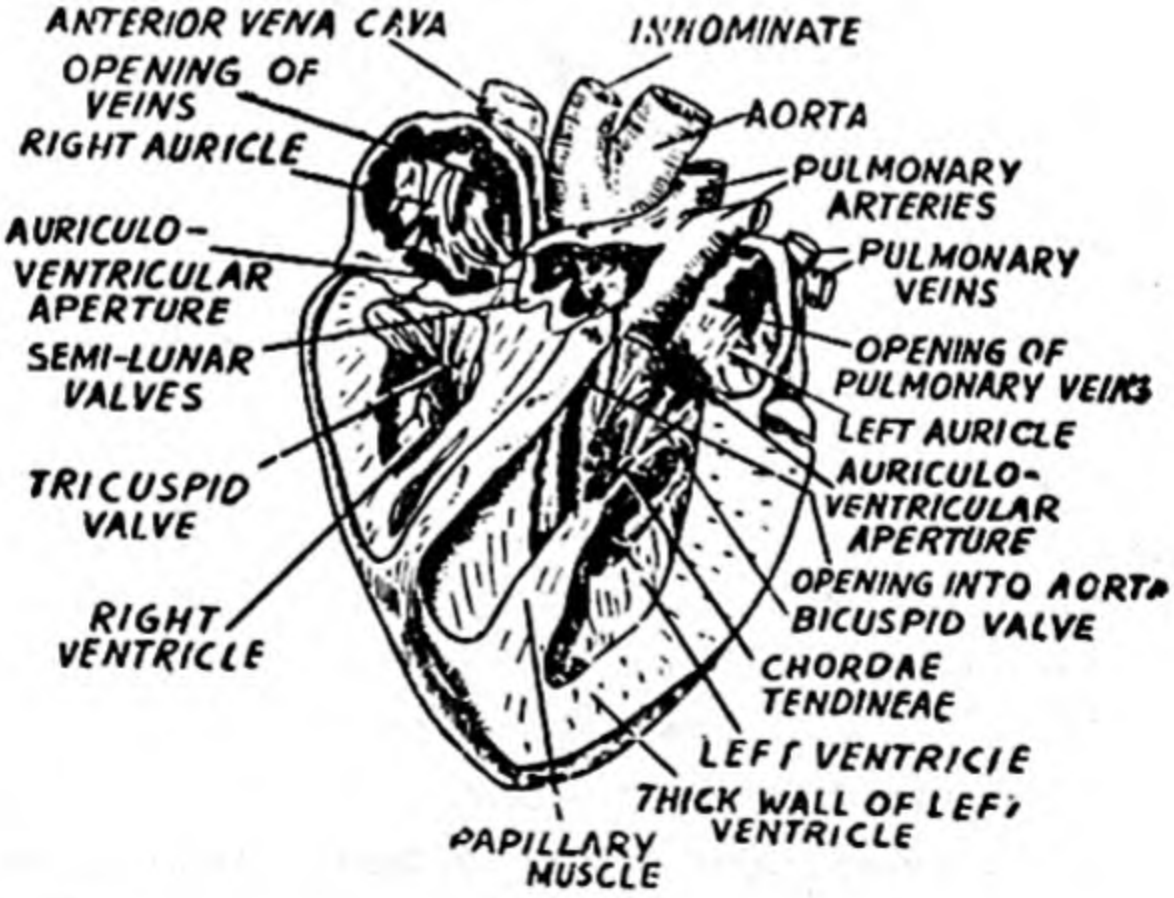
Blood Vascular System. The *heart* (Fig. 158) lies in the middle of the thorax, enclosed in the *pericardium*, consisting of parietal and visceral layers. The cavity between the two layers is filled with the *pericardial fluid*. The heart of the rabbit shows a distinct advance over that of the frog for, in addition to the two auricles, there are two ventricles separated from each other by a ventricular septum. As a result of this there is complete separation between the aerated and non-aerated blood in the heart. The sinus venosus and the truncus arteriosus are both absent. Consequently the three venae cavae open directly into the right auricle, and the aorta and the pulmonary artery arise directly from the left and the right ventricles respectively.

The auricles have thin walls but the ventricles, particularly the left one, have thick and muscular walls. The two auriculo-ventricular apertures are guarded by valves which permit the flow of blood only in the direction of ventricles. The valve on the left side consists of two membranous flaps and is known as the *bicuspid* or *mitral valve*, while that on the right side is made up of three flaps and is called the *tricuspid valve*. The free edges of the flaps are connected with the *papillary muscles*, projecting from the walls of the ventricles, by tough tendinous cords or *chordae tendineae*, which prevent the valves from being pushed into the auricles by the pressure of the blood during the contraction of the ventricles. The openings of the aorta in the left ventricle and the pulmonary artery in the right ventricle are each guarded by three semilunar valves, which prevent the flow of blood backwards into the corresponding ventricle.

Let us now study the action of the heart and the course of the blood through its various chambers (Fig. 159). The non-aerated blood from the body is brought to the right



A



B

ig. 158. Heart of the sheep. A, ventral view ; B, dissected from the ventral side. (After Jepson).

auricle by the three venae cavae which have separate openings into the auricle. The right auricle contracts and drives the

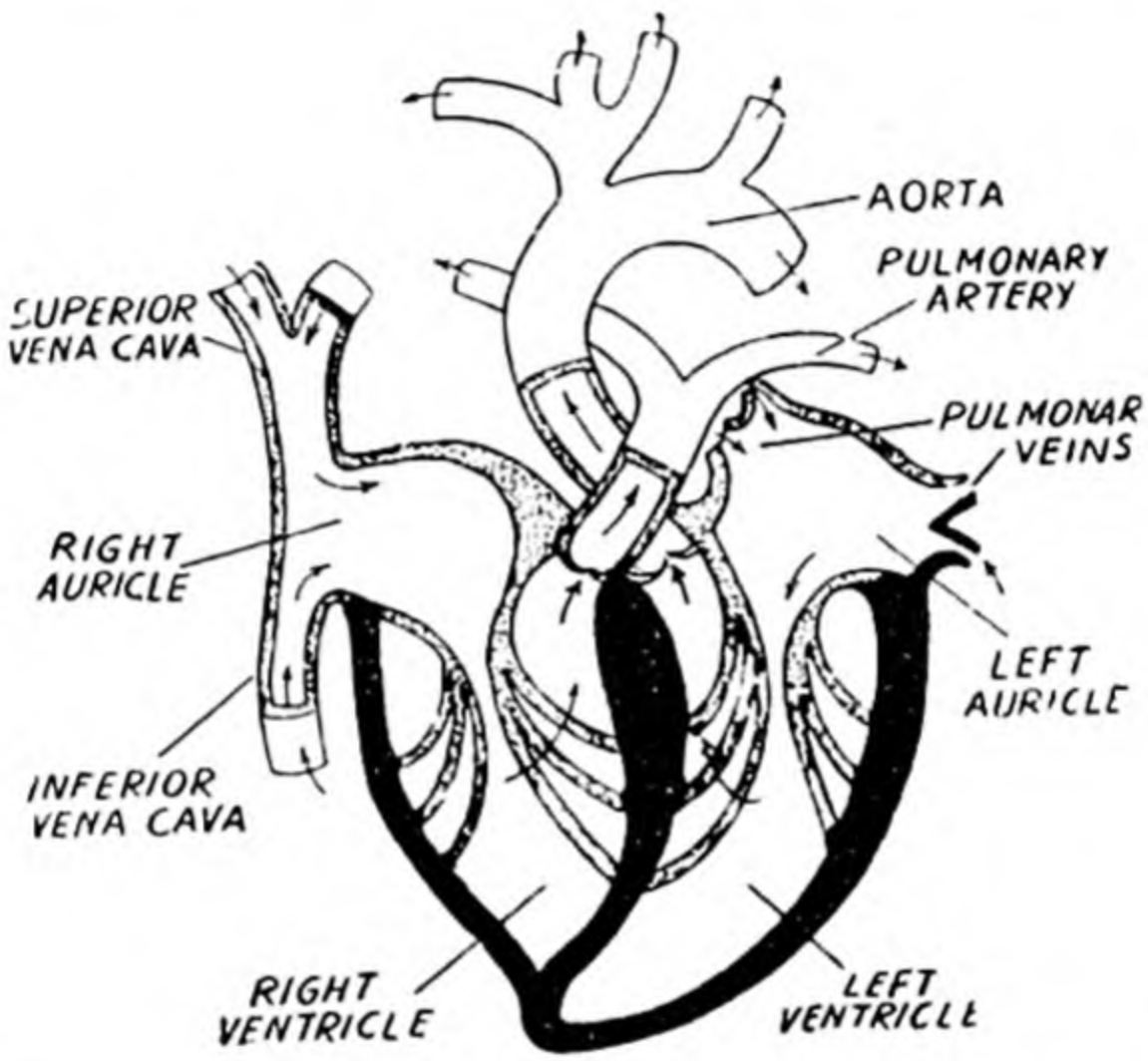


Fig. 159. Diagram of the mammalian heart to show the course of the blood through the various chambers.

blood, through the tricuspid valve, into the right ventricle which then contracts and pushes the flaps of the tricuspid valve over the auriculo-ventricular aperture, thus closing it completely. The blood is, therefore, forced into the pulmonary artery which takes it to the lungs for oxygenation. From the lungs the oxygenated blood is returned to the left auricle by the two pulmonary veins which have a common opening. When the left auricle contracts, the blood is driven into the left ventricle through the bicuspid valve. The left ventricle then contracts sending the blood into the aorta, the auriculo-ventricular aperture being closed by the bicuspid valve. From the aorta

the blood is distributed to the body from where it is returned to the heart by the venae cavae. We thus see that, unlike the imperfect arrangement in the frog where the head alone receives aerated blood, in the rabbit all parts of the body receive aerated blood and the whole of the non-aerated blood goes to the lungs for oxygenation.

The *arteries* (Fig. 160) differ from those of the frog in many respects. In place of two systemic trunks there is only a single *left aortic arch* which curves round and runs back as the dorsal aorta. In the absence of a truncus arteriosus the carotid arteries arise from the aortic arch, and the pulmonary artery directly from the right ventricle. The aorta is connected with the left pulmonary artery by a small tough strand of tissue, the *ductus arteriosus* (Fig. 165), which is the remnant of a blood vessel in the embryo.

The *aorta* gives off a large number of arteries. The *innominate artery* arises from the commencement of the arch of the aorta. It gives off near its origin the *left common carot d*, and then divides into the *right subclavian* and the *right Common carotid arteries*. Sometimes the left common carotid arises directly from the aortic arch. Each common carotid divides, opposite the angle of the jaw, into the *internal carotid* which enters the skull and supplies the brain, and the *external carotid* which supplies the head and face. The subclavian of either side runs outwards to enter the limb as the *brachial artery*, after giving off the *vertebral artery* which runs through the vertebrarterial canal of the cervical vertebrae and supplies the spinal cord and the brain. A series of small paired *intercostal arteries* arises from the aorta in the region of the thorax and supplies the body-wall. In the abdominal region the aorta gives off the large unpaired *coeliac artery*, which divides into the *hepatic artery* going to the liver and *lieno-gastric* supplying the stomach and the spleen. Behind the coeliac artery arises an

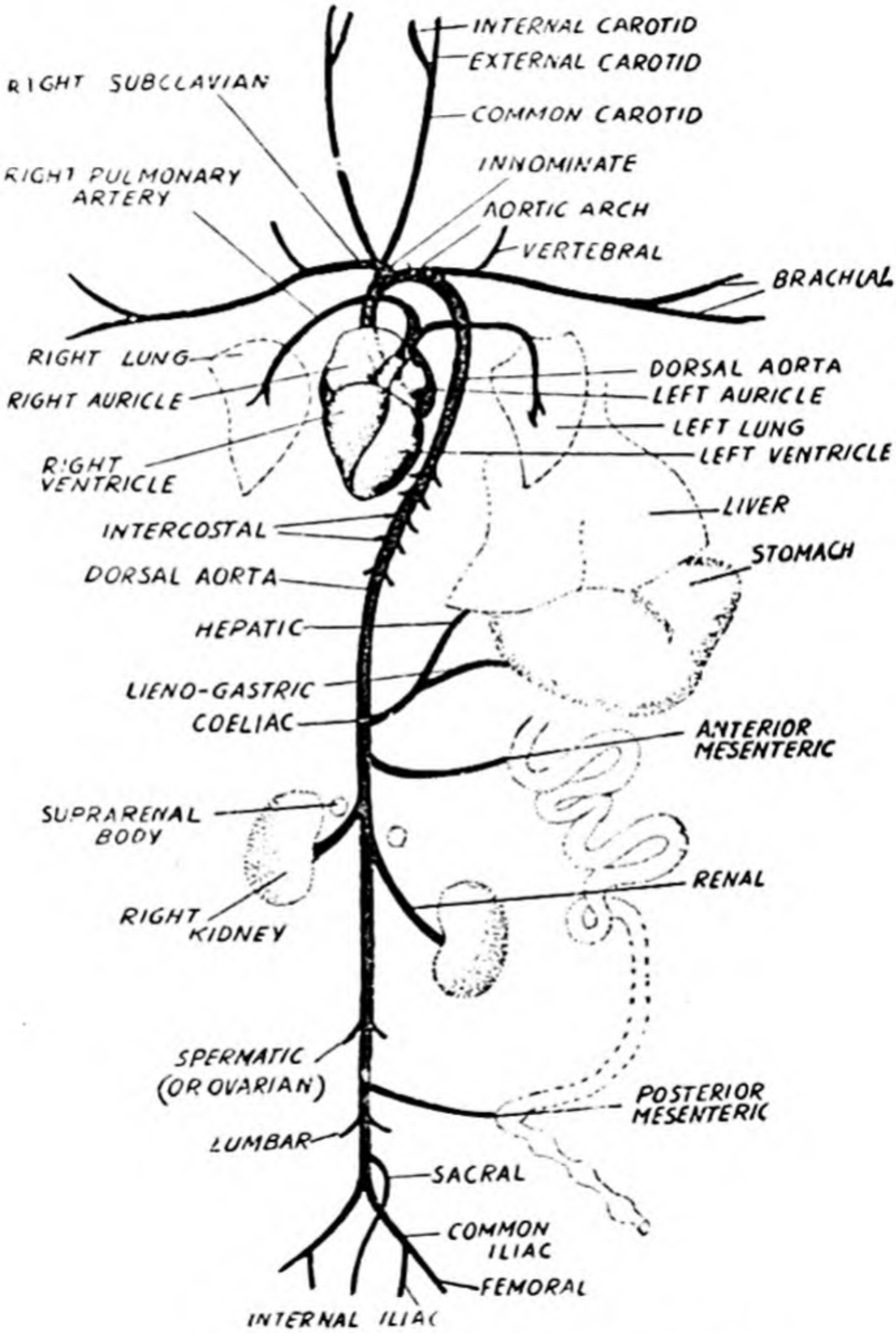


Fig. 160 Arterial system of the rabbit.

unpaired *anterior mesenteric artery* which sends branches to the small intestine, pancreas, caecum and colon. The *renal arteries*, going to the kidney, are paired, the left one arising a little behind the right one. The *spermatic arteries* in the male or the *ovarian arteries* in the female supply the testes or the ovaries. The *posterior mesenteric artery* is a small vessel arising behind the genitals. It supplies the hinder part of the rectum. The two *lumbar arteries* send out branches to the body-wall. The *sacral artery* arises behind the lumbars. It runs along the ventral surface of the sacrum and enters the tail. It corresponds to the caudal artery of other vertebrates and should, therefore, be regarded as the posterior continuation of the aorta. The two large *common iliac arteries* appear to be formed by the bifurcation of the aorta. They enter the hind-limbs and are continued as the *femoral arteries* after giving off the *internal iliac arteries* which supply the dorsal wall of the pelvic cavity.

The *pulmonary artery* arises from the right ventricle and divides into the right and left branches, each going to the corresponding lung. As already stated, the pulmonary artery, unlike other arteries, carries non-aerated blood which is aerated in the lungs.

The *veins* (Fig. 161), like the arteries, differ considerably in their arrangement from those of the frog. As a sinus venosus is absent, the three venae cavae open directly into the right auricle. The posterior vena cava is not formed at its hinder end in the region of the kidneys, as in the frog, but commences at the posterior end of the abdomen where it receives non-aerated blood from the hind-limbs and the adjacent parts. An anterior abdominal vein, therefore, is no more required and is absent. Another point worth noting is the absence of the renal portal system. The only blood entering the kidney is that brought by the renal arteries.

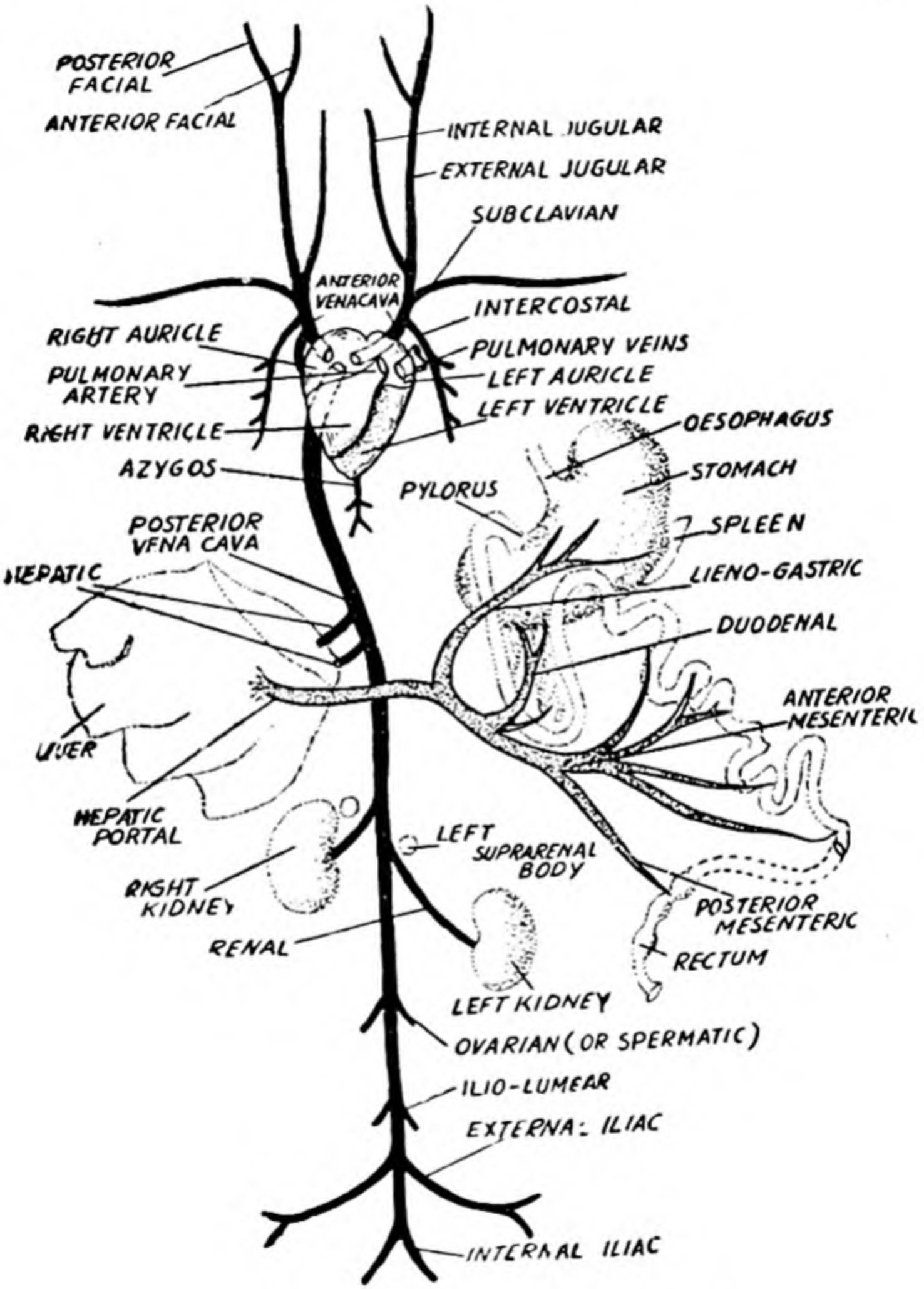


Fig. 161. Venous system of the rabbit.

Each *anterior vena cava* or *precaval* receives a number of veins, the more important of which are (1) the *internal jugular* from the brain, (2) the *external jugular* (formed by the union of the *anterior* and *posterior facial veins*) from the neck and head, (3) the *subclavian* from the fore-limb and the shoulder, and (4) the *intercostal* from some of the anterior intercostal spaces. A median *azygos vein* collects blood from the posterior intercostal spaces of both sides and opens into the right precaval close to the auricle.

The *posterior vena cava* or *postcaval* is formed by the union of two *internal iliac veins* bringing blood from the backs of the thighs. The postcaval then runs forward close to the vertebral column and receives, in turn, (1) a pair of large *external iliac veins* which are continuations of the *femoral veins* from the hind-limbs and into which open small veins from the urinary bladder, and the uterus in the female, (2) paired *ilio-lumbar veins* from the body-wall, (3) a pair of small *spermatic veins* in the male or *ovarian veins* in the female, from the testes or ovaries, (4) paired *renal veins* from the kidneys, the right being shorter than the left, and (5) a number of large *hepatic veins* from the liver when it (postcaval) passes through that organ. Anteriorly the postcaval opens into the right auricle along with the two precavals, each having a separate opening.

The *hepatic portal vein* is a large vein which collects blood from all parts of the alimentary canal and opens into the liver. It is formed by (1) the *lieno-gastric vein* from the stomach and spleen, (2) the *duodenal vein* from the duodenum and pancreas, (3) the *anterior mesenteric vein* from the small intestine, caecum, colon and the greater part of the rectum, and (4) the *posterior mesenteric vein* from the terminal portion of the rectum. As has been mentioned before, there is no renal portal system in the rabbit.

The two *pulmonary veins* return oxygenated blood from the lungs and open by a common aperture into the left auricle.

The *blood* of the rabbit (Fig. 162) differs from that of the frog in certain respects. The red blood corpuscles are much smaller in size and, instead of being oval, biconvex and nucleated, as in the frog, are circular, biconcave and non-nucleated. Moreover the temperature of the blood remains constant at about 100°F, irrespective of the temperature of the surrounding medium. The rabbit, therefore, is a *warm-blooded animal* whereas the frog, in which the temperature of the blood varies with the surrounding medium, is a *cold-blooded animal.*

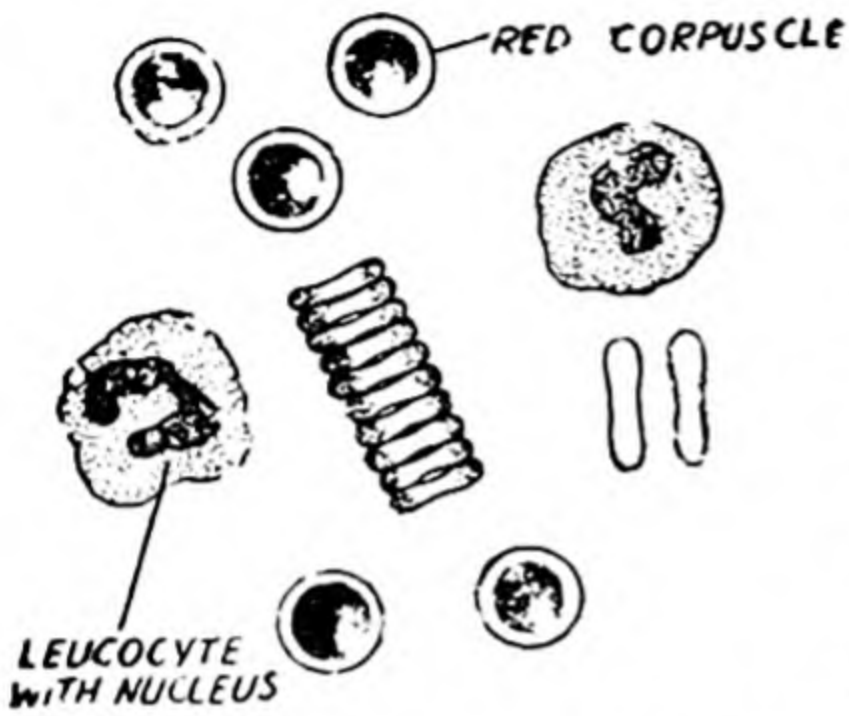


Fig. 162. Blood of the rabbit.

The *lymphatic vessels* from all parts of the body, except the right fore-limb and the right side of the head and neck, communicate with a main trunk, the *thoracic duct*, which runs through the thorax and abdomen along the left side of, and dorsal to, the aorta. Anteriorly it opens into the left subclavian veins at its junction with the external jugular. The lymphatics from the right side of the body, which are not connected with the thoracic duct, open into the right subclavian at the corresponding point. In the rabbit there are no lymph hearts.

Nervous System. The *brain* (Figs. 163 and 164) is much more highly developed than that of the frog. The *cerebral hemispheres* are relatively much larger and extend backwards to reach the cerebellum, covering the diencephalon and the optic lobes. The two hemispheres meet each other in the median line and are connected by a transverse bridge of nerve fibres, known as the *corpus callosum*. Their external surface is convex

and smooth but bears shallow lateral grooves or *sulci*. Each hemisphere may be divided into a number of lobes, namely,

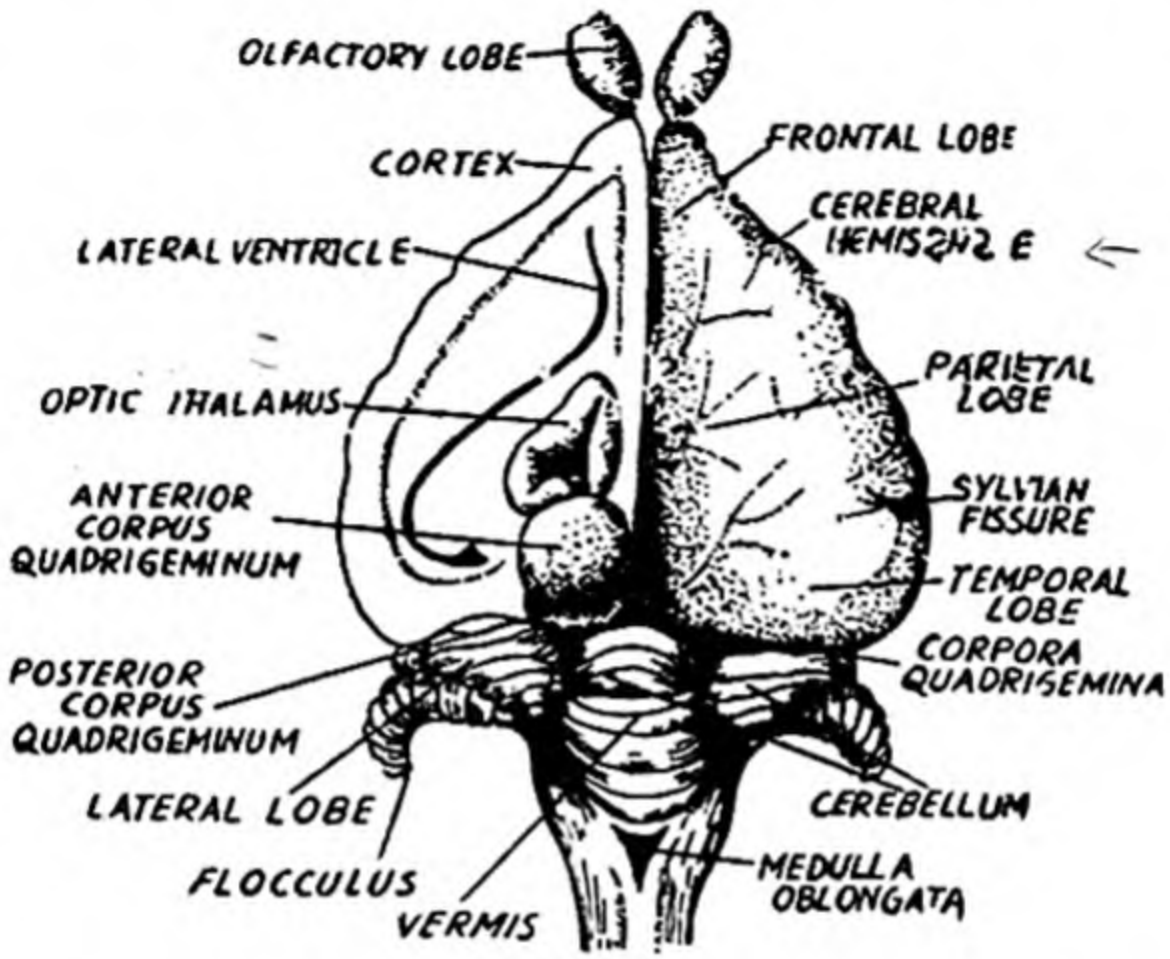


Fig. 163. Brain of the rabbit, dorsal view ; part of the left cerebral hemisphere has been cut away

(1) a narrow *frontal lobe* beginning at the anterior end and extending back along the outer side, (2) a broad *parietal lobe* behind and to the inner side of the frontal lobe, (3) a ventrally projecting *temporal lobe* in the postero-lateral region, and (4) a thick *hippocampal lobe* on the ventral side. There is a shallow oblique groove, the *Sylvian fissure*, which lies between the frontal lobe and the temporal lobe, on the outer side of each hemisphere. Another longitudinal groove, the *rhinal fissure*, on the ventral side, separates the hippocampal lobe from the temporal lobe. The cerebral hemispheres contain two shallow *lateral ventricles* which communicate with the narrow *third ventricle* through the slit-like *foramen of Monro*. A pair of solid club-shaped *olfactory lobes* projects forwards from beneath

the anterior ends of the hemispheres. They are continued behind, on the ventral surface, as two bands of nervous tissue.

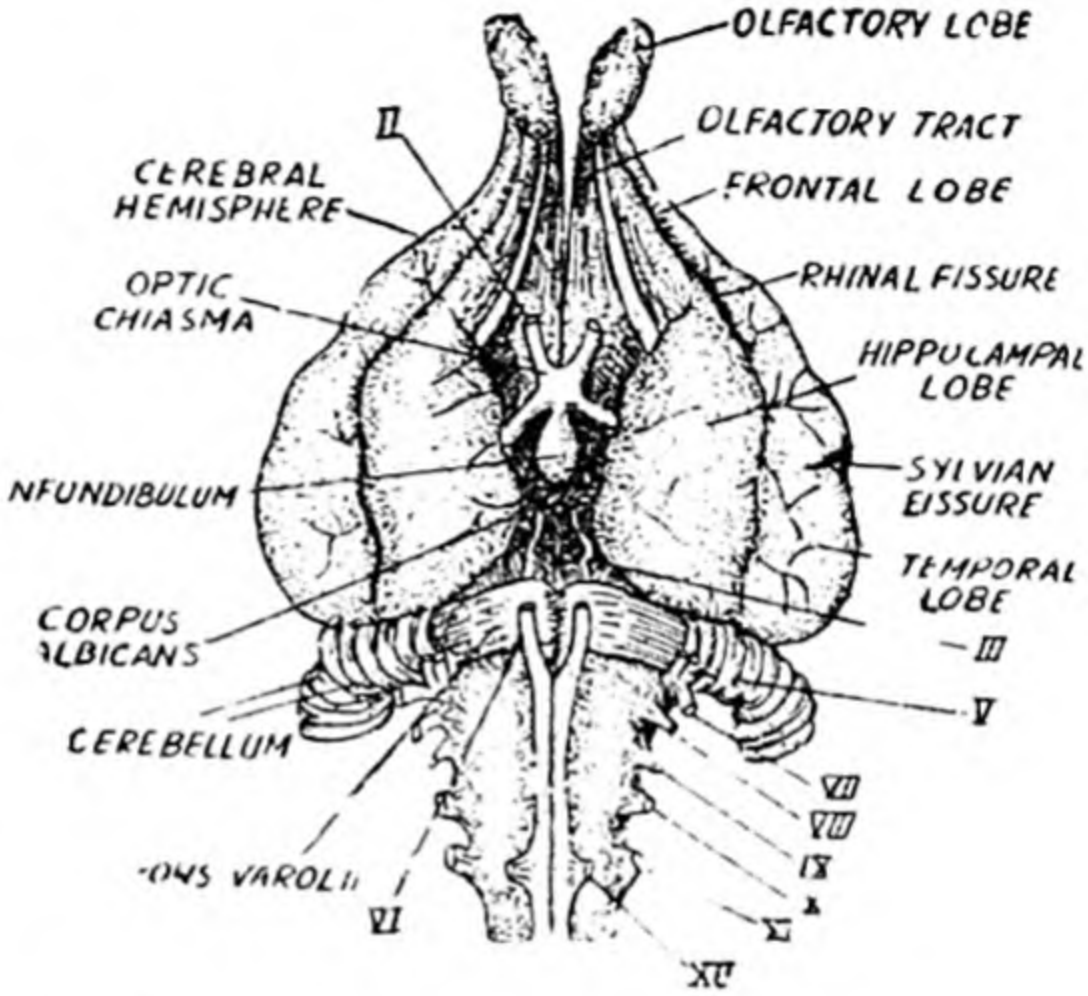


Fig. 164. Brain of the rabbit, ventral view.

the *olfactory tracts*, which posteriorly meet the hippocampal lobes.

The *diencephalon* is roofed by the thin and vascular *anterior choroid plexus* from which projects upwards and backwards the *pineal stalk*, bearing at the end the *pineal body*. The sides of the diencephalon are thickened to form the *optic thalami* while its floor is depressed to form the *infundibulum* to which the *pitu tary body* is attached. In front of the infundibulum is the *optic chiasma* and behind it is a small rounded swelling, known as the *corpus albicans*.

The *optic lobes* are solid and each is divided by a transverse fissure into two lobes, of which the anterior is much larger than the posterior. Four lobes, known as *corpora quadrigemina*, are

thus, formed. The *crura cerebri* are two strong bands of nerve fibres running forwards and outwards from the medulla to the hemispheres.

The *cerebellum* lies behind the hemispheres and is solid. It is highly developed and its surface deeply folded. It consists of a median lobe, the *vermis*, two *lateral lobes*, and two *flocculer lobes*, attached to the outer sides of the lateral lobes. The *medulla oblongata* is somewhat flattened dorso-ventrally and narrows gradully behind to merge into the spinal cord. It is roofed by the thin *posterior choroid plexus*. The cavity of the medulla or the *fourth ventricle* is fairly wide but shallow. It is connected with the *third ventricle* by a narrow *iter*. Running across the anterior border of the medulla on the ventral side, and connecting the two sides of the cerebellum with each other, is a transverse band of nerve fibres, the *pons Varolii*.

There are twelve pairs of *cerebral nerves* in contrast to ten of the frog. The first ten are similar to those of the frog with some minor differences. The *olfactory nerve* arises from the olfactory lobe by many roots which pass through the apertures in the cribriform plate. The *facial nerve* is without an ophthalmic branch, and is distributed to the muscles of the face. So it is practically a motor nerve. The *vagus nerve* (Fig. 165) arises from the medulla and after leaving the skull forms the *vagus ganglion* from which arise three nerves, namely, (1) the *anterior laryngeal*, which runs inwards to the larynx, crossing the carotid artery on the dorsal side, (2) the *depressor* which runs down the neck to the heart, and (3) the *main vagus* which runs back parallel to the depressor and passes into the thorax and thence into the abdomen giving off branches to the heart, lungs and stomach. The two main vagus nerves give off in the region of the aorta, the left and the right *recurrent laryngeal nerves*. The former loops round the ductus arteriosus and the latter round the subclavian artery, and both of them run

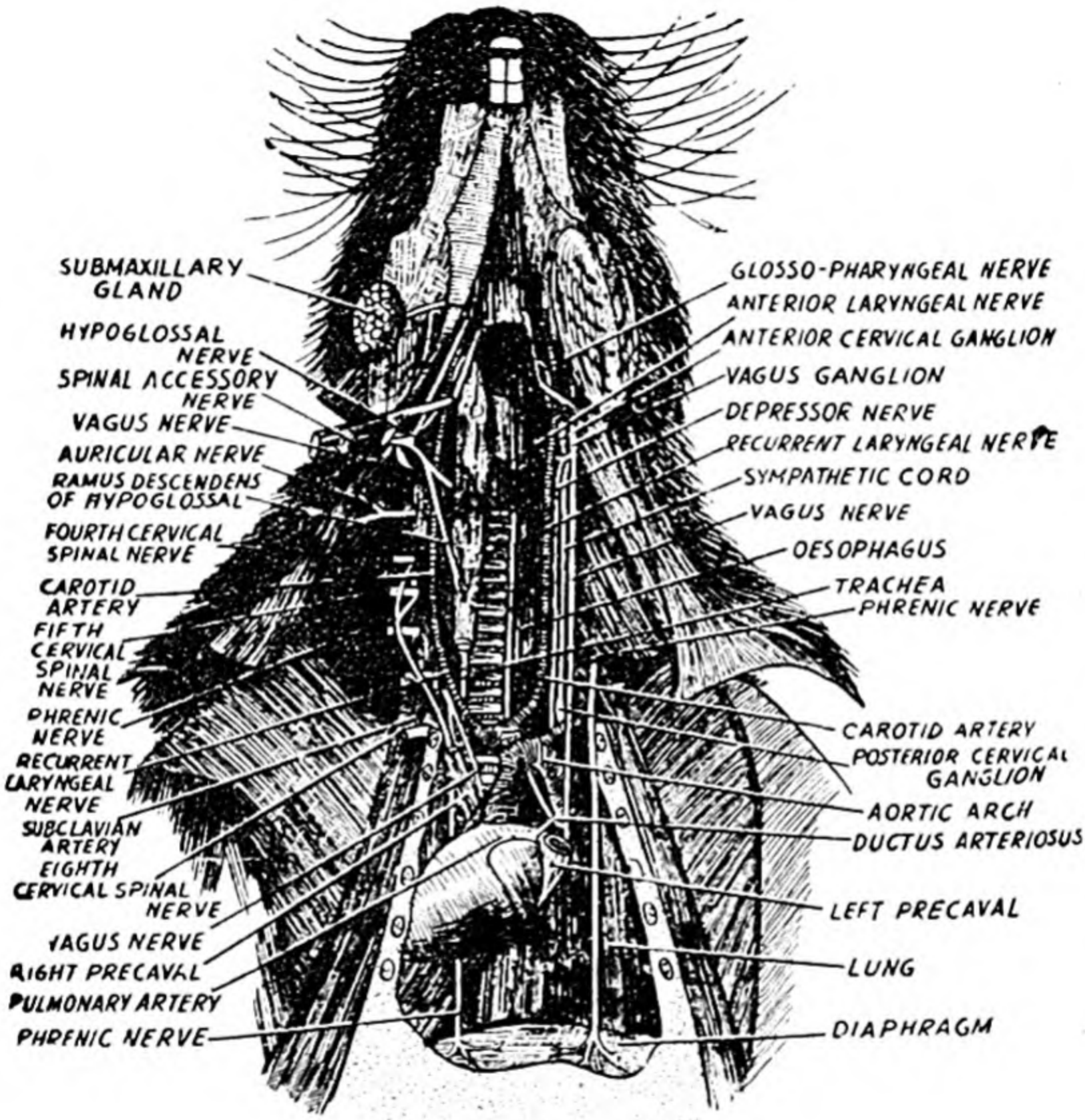


Fig. 165. A dissection of the neck and thorax of a rabbit. (After Marshall and Hurst).

forwards to the larynx. The eleventh and twelfth cerebral nerves (Fig. 165) should be regarded as spinal nerves which have gone into the head. The eleventh or the *spinal accessory* is formed by the union of nerve fibres from several of the anterior spinal nerve and from the vagus. These fibres enter the cranium through the foramen magnum before uniting to form the main nerve which arises from the side of the medulla and leaves the skull to innervate some of the muscles of the neck. The twelfth or *hypoglossal* corresponds to the first spinal nerve of the frog. It arises by a number of roots from the ventral surface of the medulla and mainly supplies the muscles of the tongue. It gives off a small branch, the *ramus descendens*, which goes to the neck.

The *spinal cord* has the same structure as has been described in the frog. It is slightly thickened opposite the fore-and hind-limbs to form the *brachial* and the *sciatic swellings* respectively, and ends posteriorly in a *filum terminale*.

There are thirty-seven pairs of *spinal nerves* which include eight pairs of *cervical*, twelve pairs of *thoracic*, seven pairs of *lumbar*, four pairs of *sacral* and six pairs of *coccygeal*. Most of them are distributed, as in the frog, to the muscles of the body-wall, and the skin. The third cervical nerve gives off a branch, the *auricular nerve*, to the external ear. The fourth cervical sends off the *phrenic nerve* (Fig. 165), which receives a branch from the fifth cervical, and runs backwards between the heart and the lung to innervate the muscles of the diaphragm. A serious injury to this nerve stops the respiratory movement of the diaphragm and causes sudden death. The four posterior cervical and the first thoracic constitute the *brachial plexus*, which gives off nerves to the shoulder and the fore-limb. Similarly the last two or three lumbar and the first two or three sacral give rise to the *sciatic plexus* which supplies nerves to the pelvic region and the hind-limb.

The *sympathetic nervous system* is more or less similar to that of the frog. Each *sympathetic cord* (Fig. 165) leaves the head close to the internal carotid and then runs down the neck alongside the common carotid. It bears an *anterior cervical ganglion* in the region of the larynx and a *posterior cervical ganglion* just before entering the thorax. In the thorax and abdomen it runs by the side of the aorta and bears swellings or ganglia, each of which is connected with a spinal nerve by a branch, the *ramus communicans*. In the posterior portion of the thorax the sympathetic ganglia give off nerves which unite to form a large *splanchnic nerve* on either side. The two splanchnic nerves pierce the diaphragm and end in a large *coeliac ganglion* lying just in front of the junction of the anterior mesenteric artery and the aorta. It is fused with an *anterior mesenteric ganglion* which lies just behind it. From these ganglia a large number of nerves radiate to supply the abdominal viscera. The ganglia and the nerves together constitute the *solar plexus*. Similarly in the hinder portion of the abdomen nerves from the sympathetic ganglia end in a *posterior mesenteric ganglion*, situated just behind the junction of the posterior mesenteric artery and the aorta. It gives off nerves to the rectum and the urinogenital organs. The ganglion and the nerves form the *posterior plexus*.

Sense-organs. The organs of touch or the *tactile organs* are present in the skin (Fig. 138). They are ovoid bodies which lie in the dermis, just below the epidermis, at the ends of nerve fibres. In addition to touch they are sensitive to heat, cold and pressure.

The *organs of smell* are situated in the olfactory capsules. The area of the olfactory epithelium lining the olfactory sacs is increased by folds of the turcinal bones. The olfactory organs, in addition to functioning as organs of smell, serve to warm and moisten the inspired air.

The *organs of taste* are lodged in certain parts of the epithelial lining of the tongue. They are groups of cells, known

as *taste-buds*, which are aggregated in little projections or papillae found most abundantly round the tip of the tongue.

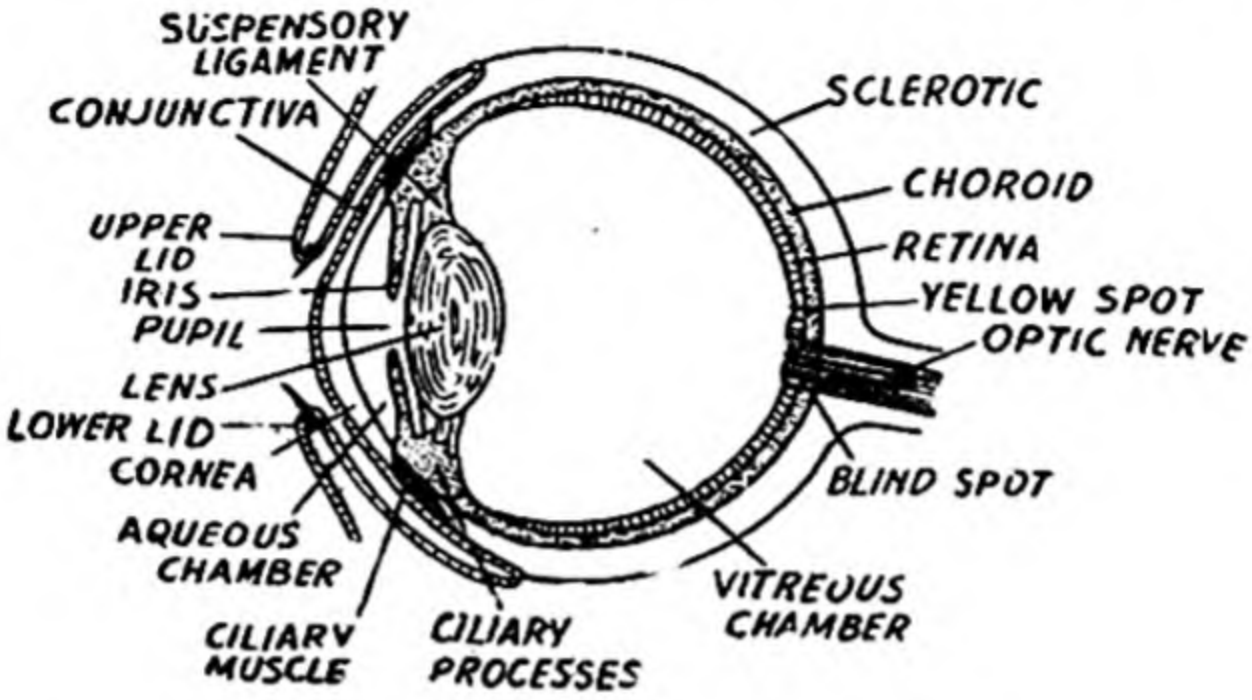


Fig 166. Vertical section of the human eye

The *eye* (Fig. 166), though built on the same general plan as that of the frog, differs from it in certain respects. The *sclerotic* is not cartilaginous but is composed of dense fibrous tissue. A *lacrymal gland* is present in the postero-dorsal angle of the orbit and a *Harderian gland* in the antero-ventral region. The secretion of these glands keeps the eye moist, thus enabling it to move freely within the orbit, and to wash away any dust, etc. that may settle on it. The excess of the secretion is carried away into the nasal chamber through the *naso-lacrymal duct* which passes through the lacrymal bone.

The *lens* is biconvex, being more convex behind than in front. The curvature of its surfaces can be changed by the contraction of the *ciliary muscle*. In this way either a near or a distant object can be clearly focussed on the retina. This power of the eye to adjust itself for varying distances is known as *accommodation*. The ciliary muscle consists of unstriped fibres and forms a ring along the junction of the sclerotic and

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the cornea. It arises from the sclerotic and is united with the *ciliary processes* which are folds of the choroid arranged radially

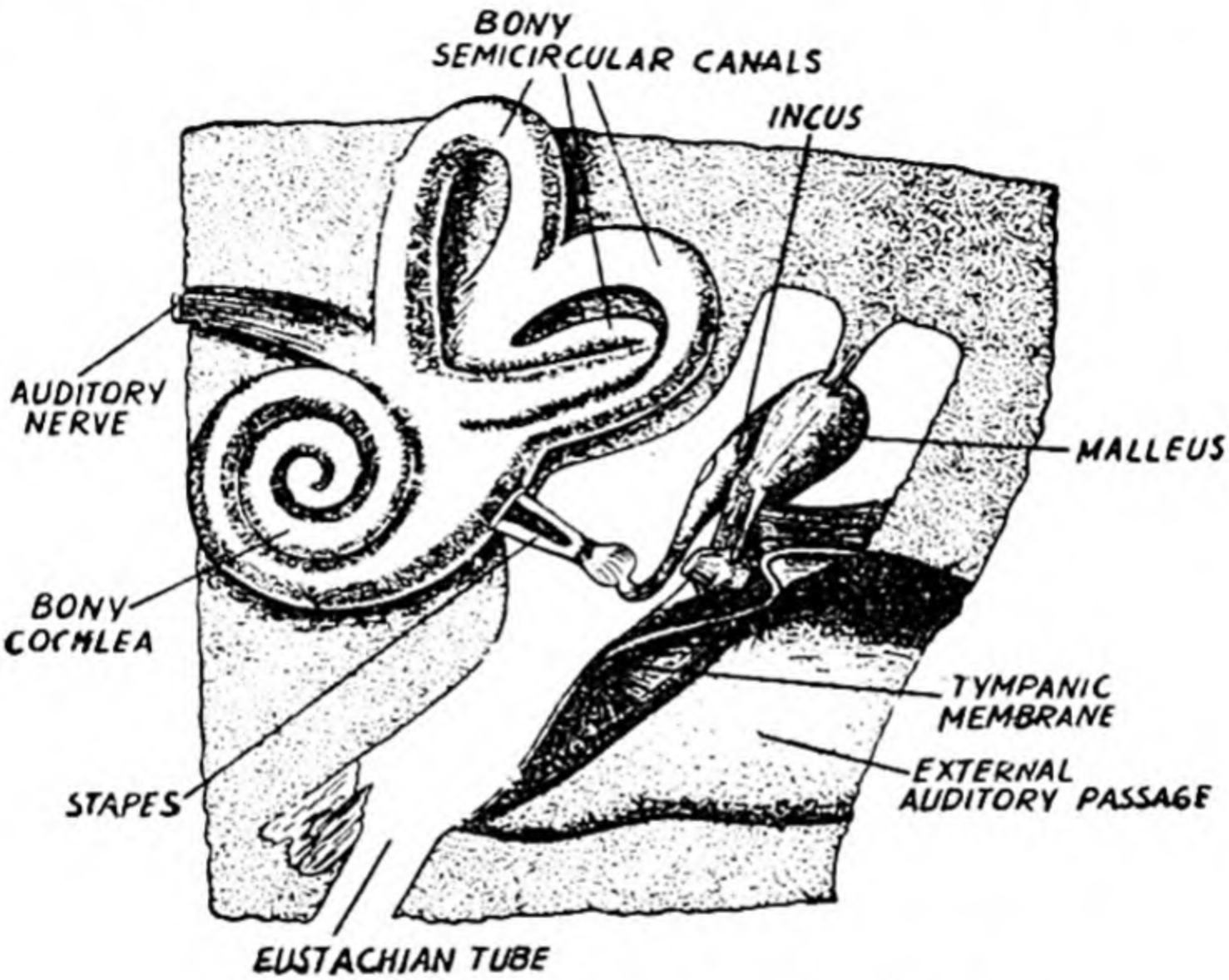

Fig. 167. The ear of a rabbit, diagrammatic.
(After Headley).

round the iris. The ciliary processes, in turn, are attached to the *suspensory ligament* which holds the lens in position. When the ciliary muscle contracts it pulls the ciliary processes, and along with them the attachment of the suspensory ligament forwards towards its origin. The suspensory ligament is, thus, loosened and its pressure on the anterior surface of the lens is decreased. As a result of this lens, through its own elasticity, becomes more convex in front. It is now adjusted for looking at near objects.

The *ear* or the *auditory organ* (Fig. 167) is more compli-

cated than that of the frog. There is an *external ear* in addition to the middle ear and the internal ear It consists of the outer movable *pinna* and the *external auditory passage* at the inner end of which is the *tympanic membrane*, separating the external ear from the middle ear. The sound vibrations are collected and concentrated by the external ear. The *middle ear* is traversed by a chain of three small bones, the *auditory ossicles*, namely, the *malleus*, *incus* and *stapes*. The malleus is attached to the inner surface of the tympanic membrane and the stapes, which is homologous with the columella of the frog, fits into the *fenestra ovalis* of the periotic bone. The incus lies between these two ossicles. The malleus corresponds to the articular bone of the lower vertebrates and the incus to the quadrate. The ear ossicles transmit the vibrations from the tympanic membrane to the internal ear through the fenestra ovalis. The cavity of the middle ear or the *tympanic cavity* communicates with the pharynx by the *Eustachian tube*. The *internal ear* consists of the *membranous labyrinth*, as in the frog. It lies in the periotic bone which forms on its inner side a *bony labyrinth* which has the same form as the membranous labyrinth which it encloses. The space between the two is filled with perilymph. The *cochlea* is much more highly developed than in the frog, and is spirally coiled. It is especially important in the rabbit as it contains the essential organ of hearing, the *organ of Corti*. This consists of a series of specially modified auditory cells on the floor of the cochlea. A branch of the auditory nerve sends fibres to these cells. The *semi-circular canals* are mainly concerned, as in the frog, with the sense of direction and the maintenance of equilibrium.

Urinogenital System. The *kidneys* are a pair of dark red bean-shaped bodies, attached to the dorsal wall of the abdomen, one on either side of the aorta. The right kidney is situated just behind the liver and the left one, due to the presence of the stomach on this side, about an inch and a half further back.

Each kidney (Fig. 168) has a notch on the inner side, known as the *hilus*, where the *ureter* leaves the kidney to open into the

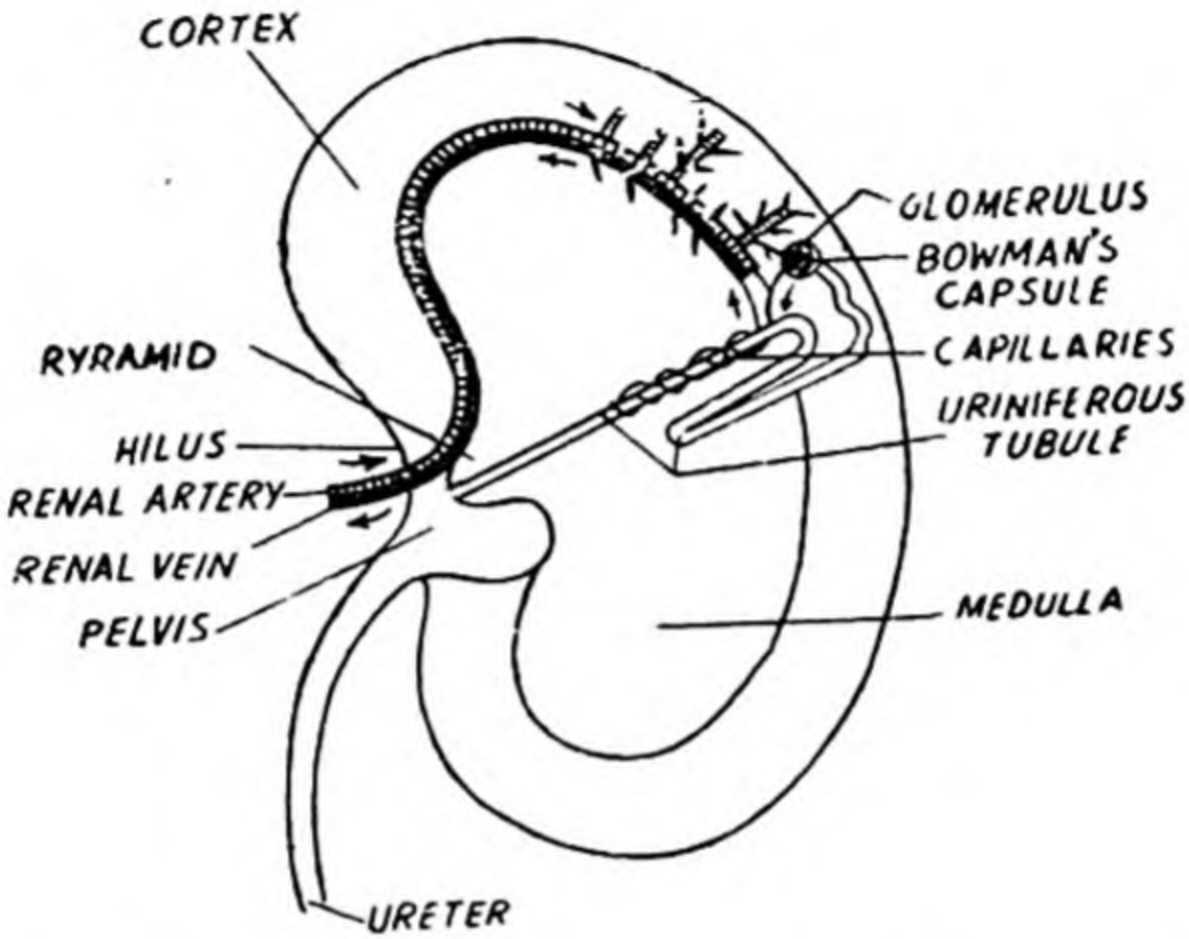

Fig. 168. Diagram to show the structure of the kidney of a rabbit in a horizontal section.

urinary bladder, at the hinder end of the abdomen. The anterior end of the ureter is expanded to form the *pelvis*, which lies inside the kidney. Each kidney, as in the frog, consists of innumerable *urinary tubules*, which are held together by connective tissue. A horizontal section of the kidney shows that it consists of two regions, a central *medulla* and a peripheral *cortex*. The cortex has a dotted appearance due to the presence in it of the *Malpighian bodies* and the convoluted portions of the tubules, while the medulla appears radially striated due to the tubules in this region being straight. Each Malpighian body consists of a *Bowman's capsule* and its *glomerulus*. The medulla on its inner side forms a conical process,

the *pyramid*, which projects into the pelvis and bears the openings of the tubules.

In the *male* (Fig. 169 A) the *testes*, in early life, lie on the dorsal wall of the abdomen close to the kidneys, a position which they maintain throughout life in the frog, but towards the approach of maturity they shift backwards and come to lie within two pouches of the body-wall, the *scrotal sacs*, which are situated on the sides of the penis. Each scrotal sac communicates with the abdominal cavity by a narrow passage, the *inguinal canal*. The spermatic artery and the spermatic vein together with some connective tissue, form the *spermatic cord* which passes from the scrotal sac into the abdominal cavity through the inguinal canal. Lying along the inner side of each testis is a mass of convoluted tubules, the *epididymis*, which communicates with the testis by very fine ducts, the *vasa efferentia*, and should thus be considered as the proximal part of the vas deferens. The epididymis is enlarged into the *caput epididymis* at the anterior end of the testis and *cauda epididymis* at the posterior end. The cauda epididymis is connected with the bottom of the scrotal sac by a short cord, the *gubernaculum*, and is continued into the vas deferens which runs forwards along the testis to enter the abdominal cavity through the inguinal canal. It then loops round the ureter of its side and runs back to open into a median sac, the *uterus masculinus* which lies on the dorsal surface of the neck of the urinary bladder. The bladder is continued posteriorly into a straight tube, the *urethra*, into which the uterus masculinus opens. The urethra traverses the *penis* and opens at its tip by the *urino-genital aperture*. As the name indicates, both the urine and the genital products pass out through this aperture. The penis projects from the ventral surface of the body in front of the anus. Its posterior wall is spongy and vascular and constitutes the *corpus spongiosum* while the anterior wall is stiff due

to the presence of two hard bodies, the *corpora cavernosa*. The free end of the penis is surrounded by a loose fold of the skin, known as the *prepuce*.

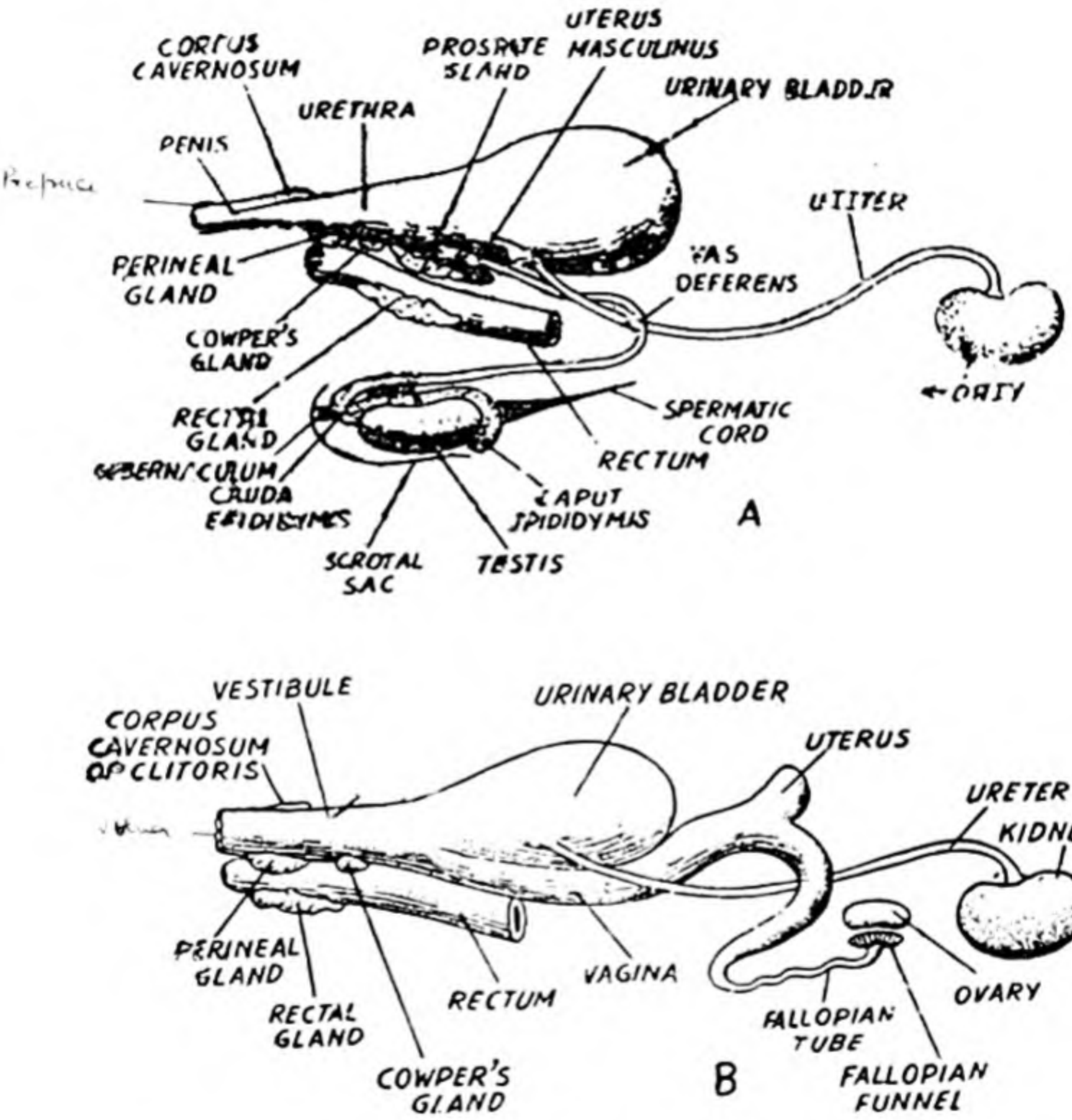

Fig. 169. Urinogenital organs of the rabbit. A, male ; B, female. (After Borradaile, slightly altered).

There are a number of accessory glands. The *prostate gland* consists of four or five lobes and is spread over the dorsal surface and the sides of the uterus masculinus. It opens by

short ducts into the urethra, which also receives, further back, ducts from a pair of small glands, the *Cowper's glands*. There is, in both sexes, a pair of small dark scent-glands, the *perineal glands*, which, in the male, lie at the sides of the base of the penis. Their ducts open at the bottom of the *perineal pouches*. A pair of *rectal glands*, also common to both sexes, is situated at the sides of the rectum.

In the *female* (Fig. 169 B) the *ovaries* are a pair of small oval bodies attached by peritoneum to the dorsal wall of the abdomen behind the kidneys. The ovarian follicles or *Graafian follicles*, as they are called in the mammals, appear as rounded projections on the surface of each ovary. Each follicle, as in the frog, contains one ovum. There are two *oviducts* and each bears at its anterior end, by which it opens into the coelom, a wide fringed *fallopian funnel*. The funnel lies close to the ovary along its outer border and is very favourably placed to receive the ova as they are shed, one at a time, by the ovary. The chances of the ova entering the funnel are further increased by a current set up towards the opening of the oviduct by the ciliated epithelium lining the funnel. The anterior narrow and convoluted part of the oviduct, next to the funnel, is known as the *fallopian tube* while its wider thick-walled posterior part is the *uterus*. The two uteri open posteriorly, by separate apertures, into a wide median tube, the *vagina*, which is continued behind into the urinogenital canal or *vestibule*. At the junction of the two is the opening of the urinary bladder. The vestibule runs back below the rectum and opens to the outside through the *vulva*. Homologous with the penis of the male is a small rod-like body, the *clitoris*, which lies in the ventral wall of the vestibule close to its external opening. The clitoris bears on its dorsal surface a pair of *corpora cavernosa*, which are smaller than those of the male.

The *Cowper's glands* lie on the dorsal side of the vestibule and are reduced, or absent. The *perineal* and *rectal glands* are

similar to those of the male. The *mammary glands* are found in the skin on the ventral surface of the body. They become swollen when the young are born and secrete milk for their nourishment till they are able to take solid food. The mammary glands are believed to be highly modified sebaceous glands.

During copulation the spermatic fluid, containing spermatozoa, is passed by the male into the vagina of the female. The sperms swim about and travel up the two uteri to ultimately reach the fallopian tubes where fertilization of the ova takes place. Each fertilized ovum begins to segment, and passes into the uterus. Here it establishes an organic connection with the uterine wall through a vascular and spongy structure, the *placenta*, in the formation of which both the embryo or *foetus* and the uterine wall take part. In the placenta the blood capillaries of the foetus come close to those of the mother. The two systems, however, remain separate and there is no mixing of foetal and maternal blood. The developing embryo is able to absorb food and oxygen, and get rid of its waste products, through an exchange of lymph. When the foetus is fully developed it is expelled from the body by the contractions of the uterine wall. The period of *gestation*, that is, the period between the fertilization of the ovum and the birth of the young, is one month. Animals, like the rabbit and man, in which the embryo develops inside the body of the mother and the young are born alive, are known as *viviparous*, in contrast to *oviparous* forms, like the frog, in which eggs are laid.

CHAPTER XXVI

PRINCIPLES OF CLASSIFICATION

Animals exist in infinite variety and incalculable numbers. They are found everywhere in different environments and having different ways of life. Already about 840,000 kinds of animals have been discovered and a considerable number is being added to the list every year. In order to study this vast assemblage of animals in an organized manner it is essential that each one of them, first of all, be given a name, and then all of them be arranged in some order. This branch of Zoology, which is concerned with the arrangement or *classification* of animals into different groups, is known as *Taxonomy* or *Systematic Zoology*.

Scientific and Common Names. It may be asked why we should give scientific names to animals when they already have common names which are easier to pronounce and remember. But the difficulty is that we do not have enough of them to serve our purpose. There are, for example, thousands of different kinds of butterflies but only a few of them, such as the cabbage butterfly, the meadow-brown, the peacock and the oak-leaf, have common names. What about the rest ? Moreover many of the common names are misleading. The jelly-fish, for instance, is not a fish nor is the water-flea a flea. Sometimes the same name is used for different animals or different names for the same animal. Due to the variety of languages spoken by people the common names of one locality cannot be understood by people of another locality. In contrast to this, scientific names are universal and are used throughout the world whatever the language of the people. So they can be understood by every one. When a scientific name is used we are certain

which particular animal is meant. Most of the scientific names of animals are derived from Latin or Greek, which are dead languages. So there is no danger of any change coming about in their meanings as often happens in the case of a living and growing language.

Basis of Classification. It is obvious that, under any scheme of classification, forms which resemble one another have to be grouped together. There are two main types of resemblances, one due to habits and environment, and the other due to relationship. The whale in appearance looks like a fish. It possesses paddles which work like fins of a fish during locomotion. But although the paddles of a whale externally look like fins they are built on quite a different plan. They are pentadactyle in structure whereas the fins of a fish are internally supported by fin-rays. Such structures, which superficially resemble each other due merely to similar habits and environment, are known as *analogous*. On the other hand, the paddle of a whale, the wing of a bird and the limb of a frog or a rabbit, though look different from one another, are all built on the same pentadactyle plan. Such structures, which are built on the same fundamental plan, even though they may differ in appearance, are known as *homologous*. It is, thus, clear that resemblances due to homology are deep-seated whereas those due to analogy are superficial.

We have had occasion before to refer to the doctrine of Organic Evolution, according to which all existing forms have gradually arisen from other simpler forms which existed before them. For instance, man and ape were evolved from a common ancestor. An ape, thus, is more closely related to man than is a horse. But man is more closely related to a horse than to a frog. We have arrived at these conclusions mainly from the study of the fundamental structure of the body in man, ape, horse and frog. So, when we attempt to classify these four

forms, we would keep the man and the ape closer together than the other two forms, of which the frog would be placed farther away. This type of classification, based on relationship as revealed by the study of evolution, is known as *natural classification* in contrast to *artificial classification* based on superficial resemblances due only to similar habits and environment. Of these two types natural classification is more rational and is the one adopted by all Zoologists, for it does not aim at cataloguing animals solely for the convenience of study but attempts to indicate relationship which exists between them. Although emphasis has been laid on the study of structure as a basis for classification, the taxonomist is aided in his work by the study of geographical distribution and development of living animals, and of fossils of extinct forms.

From the preceding paragraph it is clear that a natural classification should indicate how the various forms have evolved through the ages. Unfortunately the data available to us for working out the course of evolution is altogether incomplete. Classification, therefore, often becomes a matter of personal opinion or judgment and, as such, there is no finality about it. It is, therefore, not surprising to find different classifications of a group given by different authors or to see the classification, of one or more groups, altered by the same author in a new edition of his book. It is not possible, with our present knowledge of evolutionary history, to say with certainty which particular classification is the correct one.

System of Classification. Our present system of classification was evolved by Linnaeus (Fig. 170), a Swedish naturalist, who lived from 1707 to 1778. His famous book *Systema Naturae* was first published in 1735, but its tenth edition, brought out in 1758, is considered to form the foundation of the system which we now follow. This system is known as *binomial nomenclature*, meaning a system of two names.

According to this system each animal is given a name consisting of two words, one for the genus and the other for the species. The species is the lowest grade of classification. It is not easy to define the word species but for practical purposes it is enough to say that a species is a group of animals which inter-breed freely and produce fertile young.

Fig. 170. Carolus Linnaeus.

Let us know take up the example of the dog, which is one of the most familiar animals, in order to explain how the system of classification works. The name of the genus to which the dog belongs is *Canis* and that of the species *familiaris*. Thus the complete scientific name of the dog is *Canis familiaris* The first letter of the generic name is a capital while that of the specific name is a small letter, and both are written in italics. The dog has many *varieties*, such as Spaniel, Alsatian, Bulldog, Terrier, Greyhound. etc. (Fig. 218), which differ from one another in appearance, size and colour. But, as all varieties of the dog can interbreed, they belong to one species and not to distinct species.

Besides the dog there are other species included in the genus *Canis*, such as the wolf (*Canis lupus*) and the jackal

(*Canis aureus*). The genus *Canis* and a few others, like *Vulpes* (fox), constitute the family Canidae. Similarly the cat and cat-like animals, such as the tiger and the lion, are included in the family Felidae, the bears in the family Ursidae and the seals in the family Phocidae. The four families mentioned above, along with other families of flesh-eating mammals, are placed together in one order, the Carnivora. The order Carnivora and a number of other orders, all possessing mammary glands and hair, are grouped together into the class Mammalia. The mammals and a number of other classes, which include fishes, amphibians, reptiles and birds, constitute the sub-phylum Vertebrata, in which all the animals have a backbone. The sub-phylum Vertebrata together with three other sub-phyla, including the lower chordates, constitute the phylum Chordata or animals having at some stage of their life-history a rod-like supporting structure, the *notochord*. Finally a number of phyla make up the animal kingdom (Fig. 171). It should be noted that the names of all the groups above the genus begin with a capital letter but they are not written in italics. The complete classification of the dog may be shown in the following manner : –

Kingdom—Animalia.
Phylum—Chordata.
Sub-phylum—Vertebrata.
Class—Mammalia.
Order—Carnivora.
Family—Canidae.
Genus—*Canis*.
Species—*Familiaris*.

CHAPTER XXVII

GENERAL SURVEY OF THE ANIMAL KINGDOM

As mentioned in the last chapter, the animal kingdom is divided into a number af main groups or phyla. Of these the phylum Chordata is characterized, among other things, by the possession of a notochord at some stage in the life-history of the animal. The notochord is absent in all the other phyla which are collectively known as the Invertebrata. The animal kingdom, thus, consists of the Chordata and the Invertebrata. In this chapter a very brief survey of only the more important groups of the animal kingdom (Fig. 171) will be given.

Phylum Protozoa

The Protozoa (Fig. 172) are the most primitive animals, being the first forms of life to appear on the surface of the earth. They are unicellular organisms, that is, the body of each organism consists of a single cell. They may form colonies which, however, are made up of more or less similar and loosely connected cells, each one of them being a complete individual, independent of the colony as a whole. In the Metazoa or the multicellular animals the cells, which are of different kinds, unite to form tissues and the individuality of each cell is sub-ordinated to the general good of the whole animal. Moreover the Protozoa, being unicellular, do not exhibit any distinction between the somatic and germinal cells as is the case in the Metazoa. Although unicellular, the Protozoa are not so simple in their modes of life, as they perform within the boundaries of a single cell most of the fundamental functions characteristic of multicellular organisms. They occur in fresh water, salt waters, damp soil and as parasites inside the bodies of other animals. The Protozoa may be divided into two sub-phyla, Plasmodroma

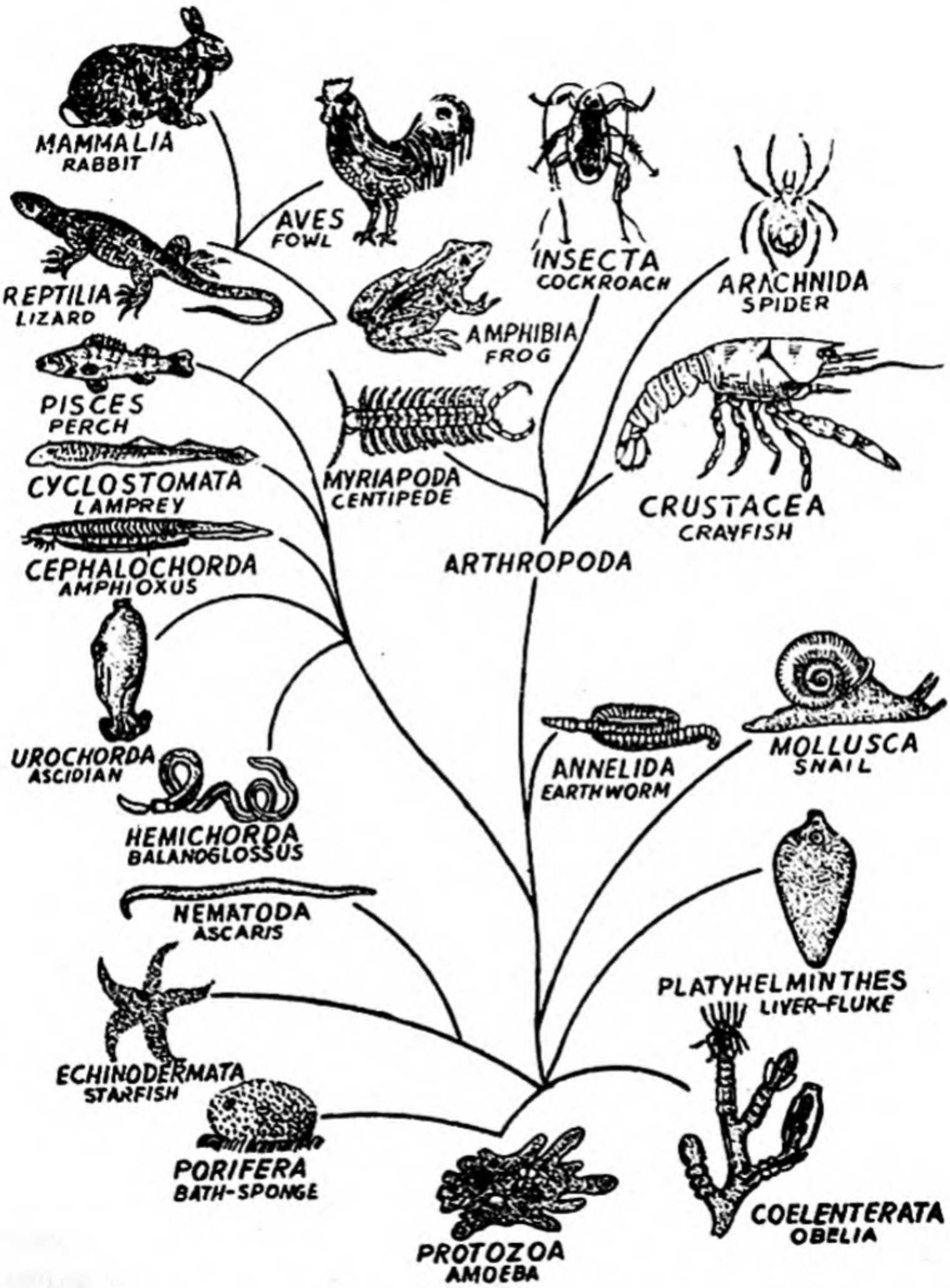

Fig. 171. A phylogenetic tree of the animal kingdom.

and Ciliophora. In the sub-phylum Plasmodroma the organs of locomotion are pseudopodia or flagella. There is either a single nucleus or many nuclei which are all alike. When syngamy or sexual union takes place there is complete fusion of the two gametes to form a zygote. In the sub-phylum Ciliophora the organs of locomotion are cilia. The nuclear apparatus consists of two nuclei, known as micronucleus and meganucleus. Thus there is nuclear dimorphism. Syngamy consists of temporary association of two individuals in which there is an exchange of nuclear material, after which they separate. The sub-phylum Plasmodroma contains three classes, namely, Sarcodina, Mastigophora and Sporozoa, and the important class of the sub-phylum Ciliophora is Ciliata.

Class Sarcodina. The class Sarcodina includes the most primitive organisms which are characterized by the presence of *pseudopodia* as organs of locomotion, and for capturing food. The pseudopodia may be blunt and finger-like, or slender and thread-like which may unite to form a net work, or narrow and stiff, radiating in all directions without uniting. The Sarcodina include both naked and shelled forms. The shell may be secreted by the animal or it may consist of foreign bodies cemented together. When secreted by the animal it is usually either chitinous or calcareous, rarely silicious.

The class Sarcodina includes both free-living and parasitic forms. *Amoeba proteus* has already been described in detail. *Entamoeba histolytica* is an important form as it is a parasite in the intestine of man, causing amoebic dysentery, in which the patient feels constant pain in the abdomen and passes blood and mucus with the faeces. The disease is caused by infected raw vegetables which are eaten without being washed with a germicide, such as potassium permanganate. The active stage of the parasite is killed by a drug, known as *emetine*, but the cysts are unaffected. If the patient after recovery is careless

with his diet he may get a relapse of the disease. The parasite is similar to *Amoeba* in structure except that its endoplasm contains red blood corpuscles of the host. *Entamoeba coli* is useful to man as the organisms feed on harmful bacteria present in the colon. The organisms belonging to the order Foraminifera possess calcareous shells of exquisite beauty and design. These organisms are constantly dying and their empty shells dropping like rain to the bottom of the ocean where they form a bed of muddy substance known as "ooze". It has been estimated that about one-third of the floor of the ocean, that is, forty million square miles is covered by this ooze. The chalk hills near the coast of England are nothing else but the ooze of Foraminifera deposited during the past millions of years.

Class Mastigophora. The organisms included in the class Mastigophora are popularly known as *flagellates*. The majority of them are free-swimming. Their distinctive feature is the possession of one or more flagella as organs of locomotion and for capturing food. A *flagellum* is a whip-like organ by the lashing movements of which the animal is propelled through the water. In many forms there may be backwardly (sometimes forwardly) directed flagella, known as *trailing flagella*, which may be either free or united to the body by a wavy or *undulating membrane*.

The class Mastigophora may be divided into two sub-classes, Phytomastigina and Zoomastigina. The organisms belonging to the sub-class Phytomastigina are plant-flagellates. They possess chloroplasts containing chlorophyll and feed like plants. This type of nutrition is called *holophytic*. The sub-class Zoomastigina is composed of animal-flagellates. The nutrition is like that of animals, that is, *holozoic*.

The commonest example of the Phytomastigina is *Euglena viridis*. It is a spindle-shaped organism and is found in fresh water ponds. In addition to the swimming movements caused

by the action of the single flagellum arising from the anterior end, it can also perform worm-like movements by contraction and extension of the body. These are known as *euglenoid movements*. There is a single nucleus. Chloroplasts, containing chlorophyll, which is an essential part of green plants, are present in the body and impart green colour to the organism. With the help of chlorophyll *Euglena* builds up carbohydrates from carbon dioxide and water, in the presence of sunlight. Towards the anterior end is a contractile vacuole which leads into a large reservoir. A bright red eye-spot, which is sensitive to light, lies close to the reservoir. An important example of Zoomastigina is *Trypanosoma gambiense*. It causes in man a disease called sleeping sickness. It is found only in Africa in certain districts of the west coast. The flagellates are found in the blood. The infection is carried by a dipterous blood-sucking fly, the tse-tse fly. In the final stages of the disease the infection spreads to the central nervous system producing in the patient a lethargic condition which accounts for the name sleeping sickness. Ultimately the patient dies. The body of *Trypanosoma* is long and wavy. The nucleus is in the centre and there is a single forwardly directed flagellum which is attached to an undulating membrane.

Class Sporozoa. The class Sporozoa includes Protozoa which are exclusively parasitic. The host may be an invertebrate or a vertebrate animal. In some cases there may be two hosts, one invertebrate and the other vertebrate. As the name indicates, the Sporozoa produce, at some stage of their life-history, resistant spores. A *spore* is a seed-like thick-walled body which offers resistance to external unfavourable conditions and contains one or more sporozoites which produce infection in the new host. In many Sporozoa there is an alternation of generations. A good example of this is *Plasmodium* or the malarial parasite, the detailed life-history of which has already been described. In *Monocystis*, which

is found in the seminal vesicles of the earthworm, there is no schizogony but only sexual reproduction. There is, thus, no alternation of generations in its life-history.

Class Ciliata. The class Ciliata includes the topical ciliates. They are the most abundant and familiar microscopic organisms. Most of them are free-living aquatic forms, found in fresh water. A few are marine. Some ciliates are parasitic but the majority of these are not harmful to the host. They are, thus, not true parasites. The mouth generally lies on the ventral surface. In addition to the locomotory cilia covering the body, there are stout cilia which drive the water, containing food, towards the mouth. The life-history of the ciliates is very simple as they retain the same form at every stage, but they show the greatest amount of cellular differentiation within a single cell, and may be considered as the highest group of the Protozoa. The distinction between the vegetative and the generative portions of the nuclear apparatus may be compared to the differentiation of the somatic and the germinal cells in the Metazoa. Reproduction usually takes place by binary fission, and also by conjugation.

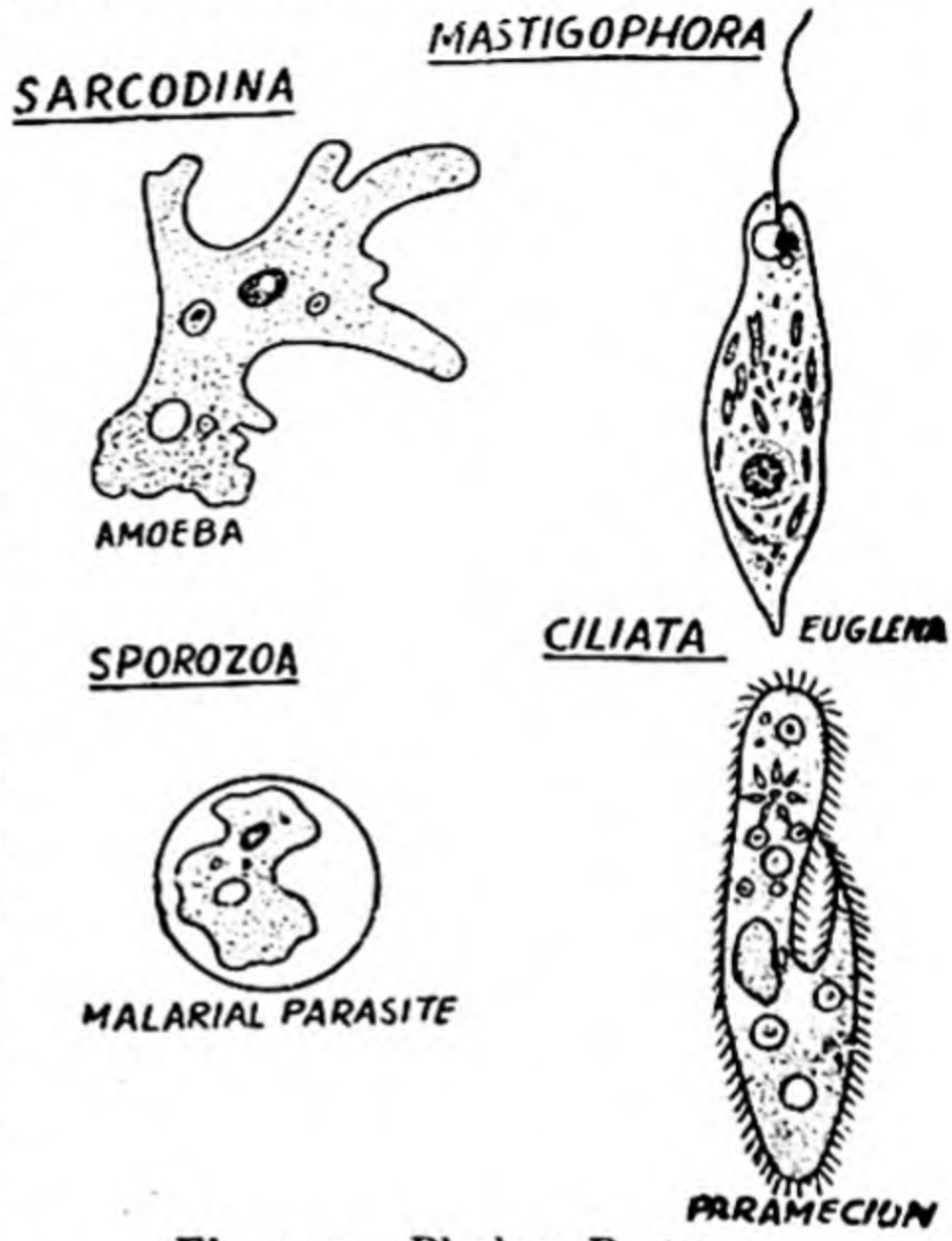

Fig. 172. Phylum Protozoa.

The best-known example of the Ciliata is *Paramecium*, which has already been studied in detail. *Vorticella* is a fixed form, commonly found in fresh water ponds. Its vase-like body is attached to the substratum by a long contractile stalk. As it does not move about the locomotory cilia are absent.

Phylum Porifera

The Porifera are commonly known as *sponges*. They are lowly organized, aquatic and fixed forms, attached to rocks, shells and other solid objects in the water. They were once thought to be plants and their animal nature was not recognised until about the middle of the last century. Being near the bottom of the animal kingdom, and not in the direct line of evolution, they have been separated from the rest of the Metazoa, and placed in a separate sub-kingdom, known as the Parazoa.

The sponges vary greatly in size, shape and colour. They have a diameter ranging from a millimetre to six feet. They may be vase-like, globular, branched or irregular in shape. Many of them are grey or dull-coloured but others are gorgeously coloured in shades of red, orange, yellow or blue. Most of them are found in the sea, up to a depth of three to four miles, but a few, belonging to a single family, spongillidae, occur in fresh water.

The name Porifera refers to the innumerable pores found in the walls of a sponge. The common bath-sponge (*Euspongia*), with which we are all familiar, is the flexible skeleton of a marine sponge, after the living tissues have been removed. Sponges, as a rule, possess a skeleton consisting of spicules which may be calcareous or silicious, but in the bath-sponge, and a few others, the skeleton consists of a fibrous material, known as *spongin*. That is why a bath-sponge is so soft and flexible

A simple sponge (Fig. 173), of which *Leucosolenia* is a common example, is generally cylindrical or vase-shaped. It is hollow from within, the cavity being known as the *paragastric cavity*, which opens to the exterior at the upper end by a fairly large aperture, the *osculum*. The wall of the sponge is pierced by a large number of minute pores, the *ostia*, which lead into the paragastric cavity. In the living sponge a current of water is constantly flowing in through the ostia and, passing through the paragastric cavity, is flowing out through the osculum. The sponge is, thus, able to take out oxygen and food material from the water when it flows through its body, and give out waste products. In the complex types of sponges the walls are much thicker, containing branching systems of canals through which the water enters the paragastric cavity.

Fig. 173. Phylum Porifera.

Phylum Coelenterata

The phylum Coelenterata (Fig. 174) includes the fresh water polyps, zoophytes, jelly-fishes, sea-anemones and corals, They are multicellular, mostly marine animals, and are radially symmetrical. The body has a single cavity, the *coelenteron*, which represents both the enteric cavity and the body-cavity of the higher Metazoa, with a single opening, the mouth, at one end. The body-wall consists of two layers of cells, an outer ectoderm and an inner endoderm with a non-cellular membrane, the mesogloea, between the two. The Coelenterata, thus, are two-layered or *diploblastic* animals, and in this character they differ fundamentally from the higher Metazoa, in which a third layer of cells, the mesoderm, is developed between the ectoderm and the endoderm, and which are, thus,

three-layered or *triploblastic* animals. These two groups are also known as the *Diploblastica* and *Triploblastica*. Most of the coelenterates possess stinging cells, known as *nematocysts*. Two types of body-form are met with amongst the Coelenterata, the *hydroid* (polyp) and the *medusoid* (medusa). The hydroid is usually fixed and may be solitary or colonial. As a rule it reproduces asexually by budding. The medusoid is always solitary and free-swimming. It reproduces sexually. The important classes included in the phylum Coelenterata are Hydrozoa, Scyphozoa and Actinozoa.

Class Hydrozoa. The class Hydrozoa includes mostly small animals which typically occur in both hydroid and medusoid forms and exhibit an alternation of generations in the life-history. The gastric filaments, present in the class Scyphozoa, are absent. The medusa has a velum. The reproductive cells are discharged directly into the water. The hydroids form extensive colonies like *Obelia*. *Hydra* is an exception and has also other features of special interest. It is solitary and free, and has no medusoid form. It is one of the very few examples of fresh water coelenterates. Some forms, like *Millepora*, secrete a massive skeleton of calcium carbonate into which the zooids can be retracted. Others form floating colonies containing various kinds of zooids performing different functions. In *Physalia* or the "Portuguese Man-of-War" one of the zooids becomes inflated to form the float and others are modified for feeding, protection and reproduction. This phenomenon is known as *polymorphism*.

Class Scyphozoa. The Scyphozoa are medusoid Coelenterata, possessing endodermal *gastric filaments*. The gonads lie in the endoderm and the sexual cells are shed into the enteric cavity, from where they pass out through the mouth A true velum is absent. There is no alternation of generations in the true sense.

The Scyphozoa include the jelly-fishes which are generally found floating at or near the surface of the sea. Their food consists of small fishes, crustaceans and other coelenterates. They swim by contractions of the umbrella. The common jelly-fish *Aurelia*, has a saucer-shaped umbrella about three inches in diameter. The edge of the umbrella is beset with numerous tentacles. From the corners of the four-sided mouth arise four tapering *oral arms* which hang down when the animal is floating. There are four horseshoe-shaped gonads. The radial canals are extensively branched. One of the most beautiful jelly-fishes, and the commonest for met with in the Indian Ocean, is *Rhizostoma* (*Pilema*). It is much bigger than *Aurelia*. The tentacles are absent. The four oral arms by longitudinal divisions become eight in the adult. There is no regular mouth but hundreds of funnel-like openings are present on the oral arms and these serve as mouths.

Class Actinozoa (Anthozoa). The Actinozoa are Coelenterata in which there is only the hydroid form, the medusoid form being absent. There is no alternation of generations. There is a *stomodaeum*, lined by ectoderm. It is short tube into which the mouth opens and which leads at the other end into the coelenteron. *Mesenteries* in the form of radiating partitions arise from the body-wall, some of which are joined with the stomodaeum. The free edges of the mesenteries below the stomodaeum are thickened to form the *mesenterial filaments*. The gonads are situated on the mesenteries and are discharged into the coelenteron. Some forms are solitary but the majority form varied and extensive colonies. Nearly all of them are sedentary in habit. The skeleton consists of either calcium carbonate or a horn-like material. In some forms the skeleton is absent.

The Actinozoa are large group including sea-anemones, corals, sea-pens and sea-fans. Sea-anemones are mostly solitary forms and abundantly found on the sea-shore in

shallow water attached to rocks or other objects generally in groups. They are often beautifully coloured. They have

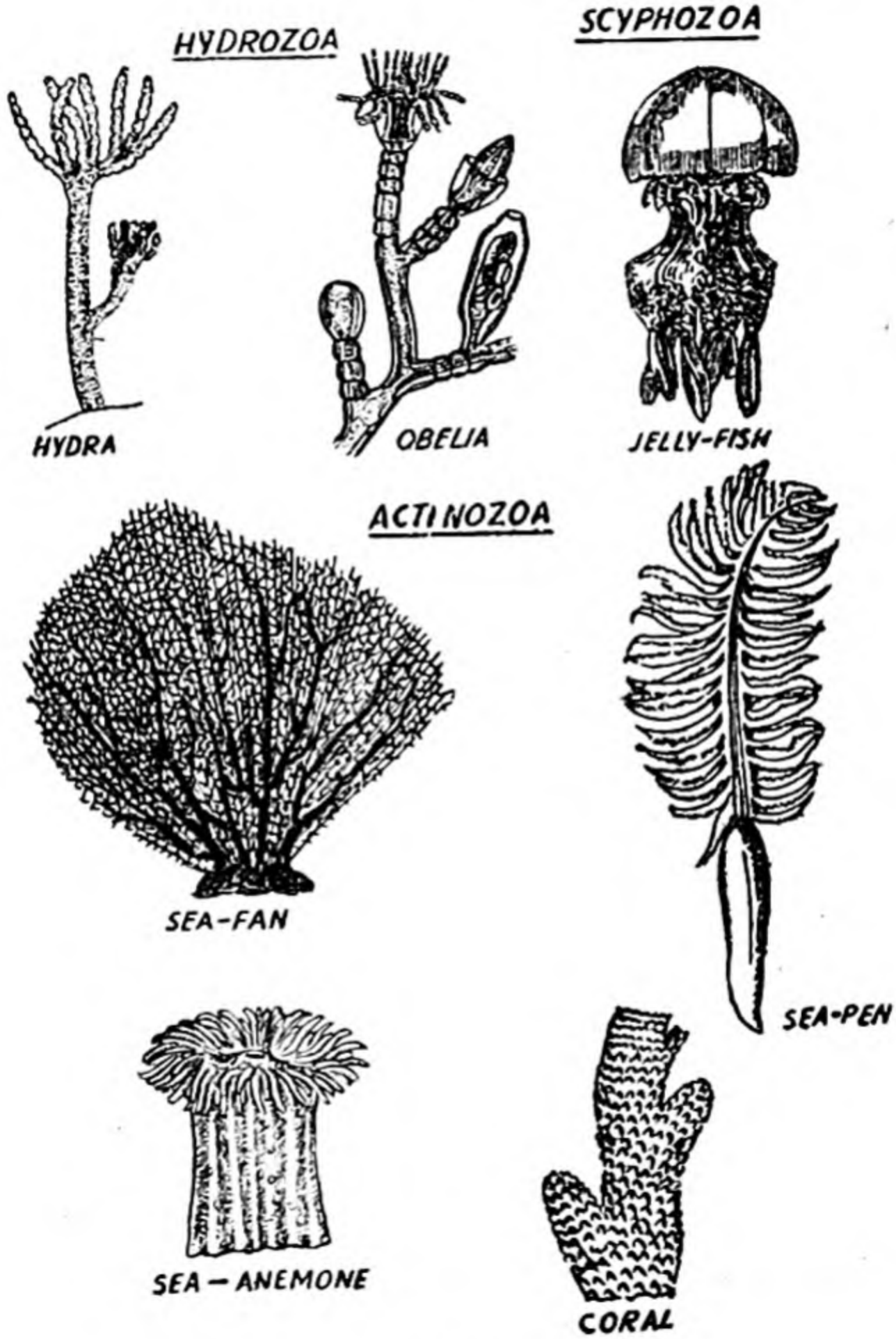

Fig. 174. Phylum Coelenterata.

no skeleton. The body is in the form of a cylinder. The mouth is in the centre of the top or *disc*, surrounded by numerous short tentacles. The body and the tentacles can be retracted or extended to a considerable extent. The animal can also very slowly change its place of attachment. Sea-anemones are often found attached to gastropod shells containing hermit crabs This association is beneficial to both parties. The crab is protected from its enemies by the sea-anemone by virtue of its stinging cells while the sea-anemone in return is carried from place to place and shares the food which the hermit crab takes. This mutually beneficial association is known as *commensalism* which is less intimate than found in symbiosis. *Alcyonium* or the "Dead-men's fingers" is a colonial form. The colony is soft and fleshy. The skeleton consists of calcareous spicules of various forms, embedded in the mesogloea. There are eight pinnate tentacles and eight mesenteries. *Gorgonia* or sea-fan consists of a branching colony, the branches being in one plane, giving the colony a fan-like appearance. The skeleton consists of a flexible horn-like material. In addition to the skeleton there are spicules present in the mesogloea. In *Pennatula* or sea-pen the colony has an elongated shape. It consists of a *stalk*, which is embedded in the sand, and a *rachis* above the stalk. The rachis bears lateral outgrowths, known as *pinnules*, which bear the zooids on the upper surface along the edges. The stalk and the rachis are supported internally by a rod of horny skeleton. The sexes are distinct. It is a phosphorescent form, that is, it emits light. The vast majority of corals have a calcareous skeleton, derived from the ectoderm. These are known as stony corals. The colonies of these corals multiply to such an exent as to cover large areas. They are then called *coral reefs*. They are generally found in shallow waters in the warmer parts of the world. The Great Barrier Reef of Australia runs along the eastern coast of Queensland and is about 1,100 miles long. The individual colonies of corals present striking variations in form.

Phylum Platyhelminthes

The Platyhelminthes (Fig. 175), popularly known as the *flat worms*, exhibit a bilateral symmetry. The body is generally dorso-ventrally compressed. The animals do not show true metameric segmentation. There are three layers in the body, namely, ectoderm, mesoderm and endoderm. Thus, these animals are triploblastic in contrast to two-layered animals, like coelenterates, which are diploblastic. An excretory system is present. There is no body-cavity or coelom. The space between the body-wall and the internal organs is filled with a special kind of connective tissue, known as *parenchyma*. A skeleton is absent. The animals are mostly hermaphrodite. They include both free-living and parasitic forms which may be either external or internal parasities. The phylum Platyhelminthes may be divided into three classes : Turbellaria, Trematoda and Cestoda.

Class Turbellaria. The Turbellaria are mostly free-living flat worms, found in fresh water, salt water or in moist earth. The body is generally leaf-like and coverd with cilia by means of which the animal glides over the substratum. A digestive cavity is present.

A common example of this class is *Planaria*. The body is elongated with a broad anterior and a pointed posterior end. The colour is variable but is generally dark brown. The length is a few millimetres. On the dorsal surface, close to the anterior end, are two black spots, the eyes. The mouth lies on the ventral surface a little behind the middle of the body. Behind the mouth is the genital aperture. *Planaria* feeds on small crustaceans, insect larvae and small worms.

Class Trematoda. The Trematoda, commonly known as *flukes*, include all parasitic forms which may be either external or internal parasites. They do not possess cilia. On account of their parasitic mode of life they possess organs of

adhesion in the form of hooks and suckers. The digestive system is well-developed.

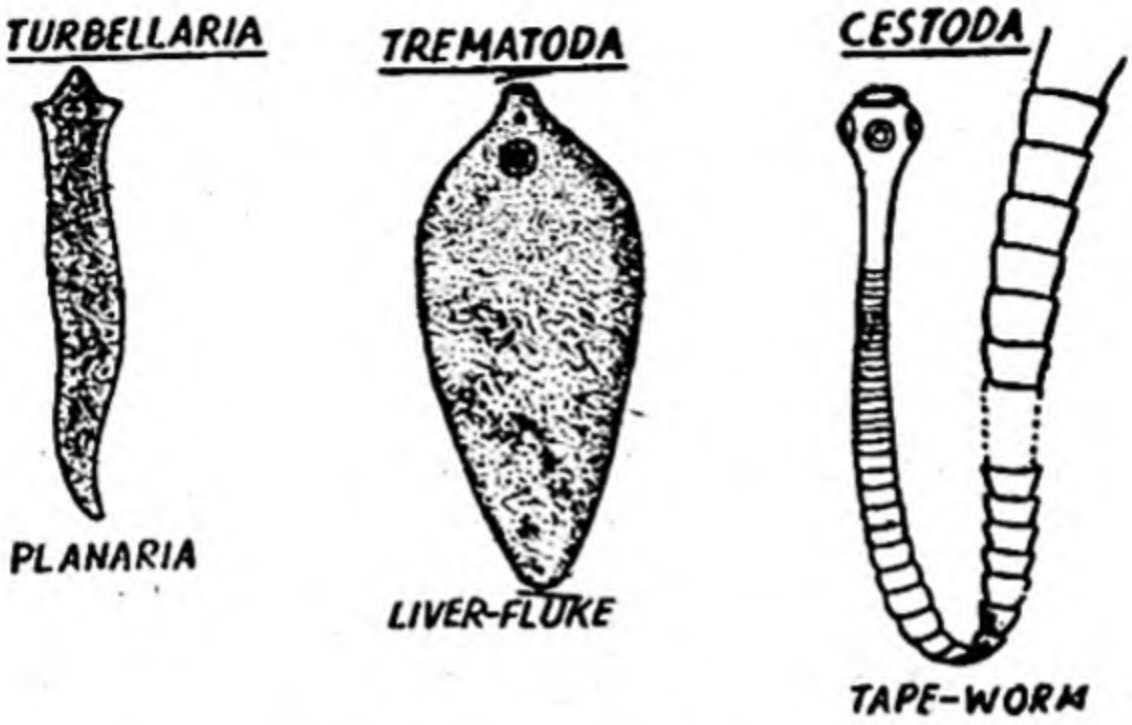

Fig. 175. Phylum Platyhelminthes.

A typical example of the class Trematoda is *Fasciola hepatica*, the liver-fluke of the sheep. The parasite lives in the bile-ducts of the sheep and causes the disease known as liver-rot. The body of the fluke is leaf-like and measures about an inch in length. It is produced anteriorly into a triangular *head-lobe*. At the anterior end is a muscular sucker containing the opening of the mouth. Another larger posterior sucker lies on the ventral surface a little behind the anterior sucker. Between the two is the genital pore. At the posterior end of the body is the single excretory pore. The external surface of the body is devoid of cilia, but bears small papillae arising from the cuticle. The life-history of the liver-fluke exhibits alternation of hosts. The young stages are passed in the interior of a water-snail and the adult stage inside the liver of the sheep.

Class Cestoda. The Cestoda or *tape-worms* are internal parasites, generally found in the alimentary canal of various animals. They are degenerate members of the phylum and

show perfect adaptation to a parasitic mode of life. The body is ribbon-like, and cilia, sense-organs and the alimentary canal are absent. In most cases they are provided with a distinct head bearing organs of adhesion, followed by a neck, and a body consisting of a number of segments or *proglottides*, each containing a complete set of the male and female reproductive organs.

The best example of the Cestoda is *Taenia solium*, the common tape-worm of man. It occurs as a parasite in the intestine of man, and may be several yards long. It has a minute knob like head or *scolex* (Fig. 176), bear ng four muscular suckers on the sides and a circlet of hooks on the elevated tip or *rostellum*. By means of the hooks and suckers it attaches itself to the lining of the intestine. Behind the head is a short neck followed by 800—900 *proglottides*. New proglottides are formed in the neck by budding. At first they are small and indistinct but, as they grow in size and mature. The oldest proglottides, consequently, are towards the posterior end. The body is covered with a thick cuticle secreted by ectodermal cells which, however, have sunk into the parenchyma Below the cuticle is a layer of longitudinal muscles. and then a layer of circular muscles which are incomplete at the edges and which enclose the nervous, excretory and reproductive systems. An alimentary canal is absent. the digested food in the intestine of the host being absorbed through the body-wall. The nervous system consists of a nerve-ring in the scolex with nerves to the suckers and the rostellum, and two chief longitudinal nerves. The exeretory

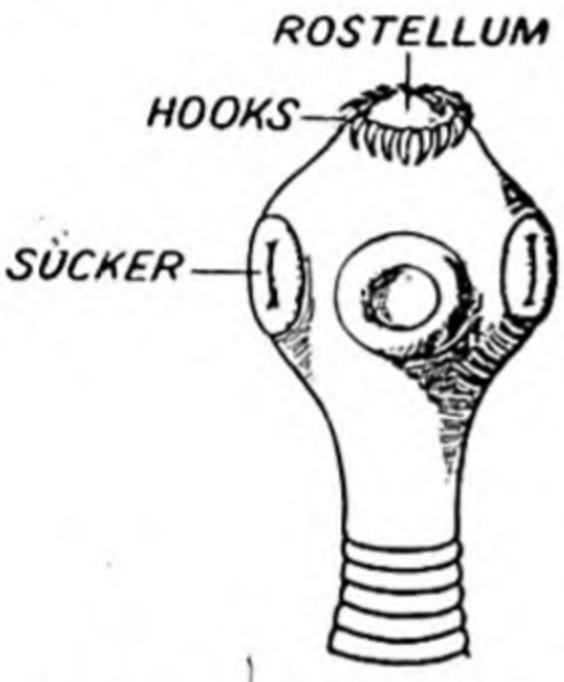

Fig. 176. Scolex of *Taenia solium*.

system is made up of two main longitudinal canals connected by a transverse canal in each proglottis, situated along its

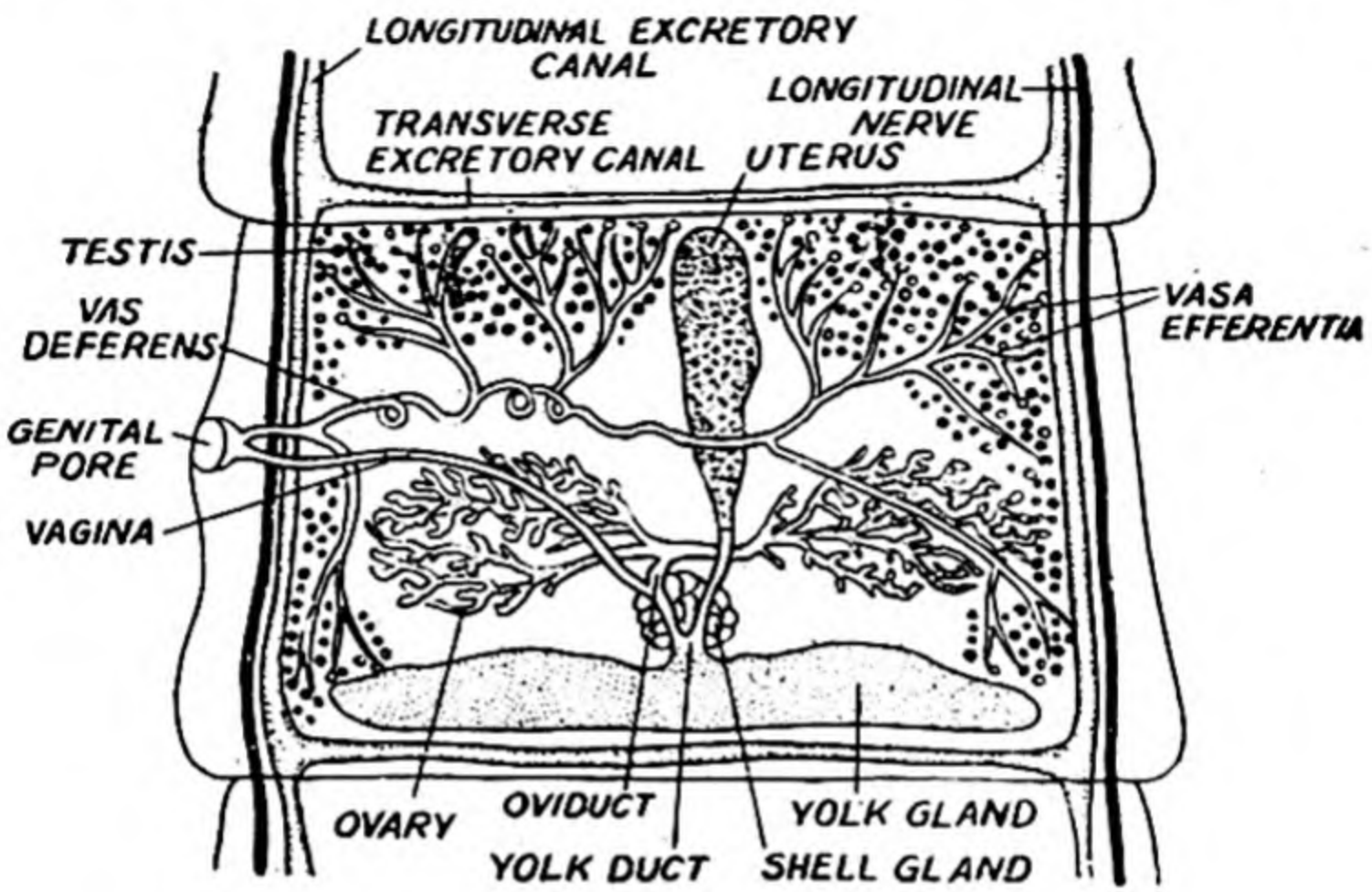

Fig. 177. A proglottis of *Taenia solium*.

posterior border. The hinder-most transverse canal has a median excretory pore. The excretory canals give off branches which end in flame-cells. A *flame-cell* has a central cavity containing a bundle of flickering cilia which drives the waste substances, in solution, into the tubules and thence to the excretory canals, to be eliminated through the excretory pore.

The tape-worm is hermaphrodite, a set of both the male and female reproductive organs being found in each segment. The two systems, however, do not mature at the same time. The male organs mature first and are, thus, more conspicuous in the anterior segments. There is a large number of *testes* from which arise fine ducts, the *vasa efferentia*, which unite to form a convoluted *vas deferens*. The latter ends in a muscular *cirrus* opening into the *genital atrium* which is common to both

systems. The genital atrium opens to the exterior by the *genital pore*. The genital pores are found alternately on the

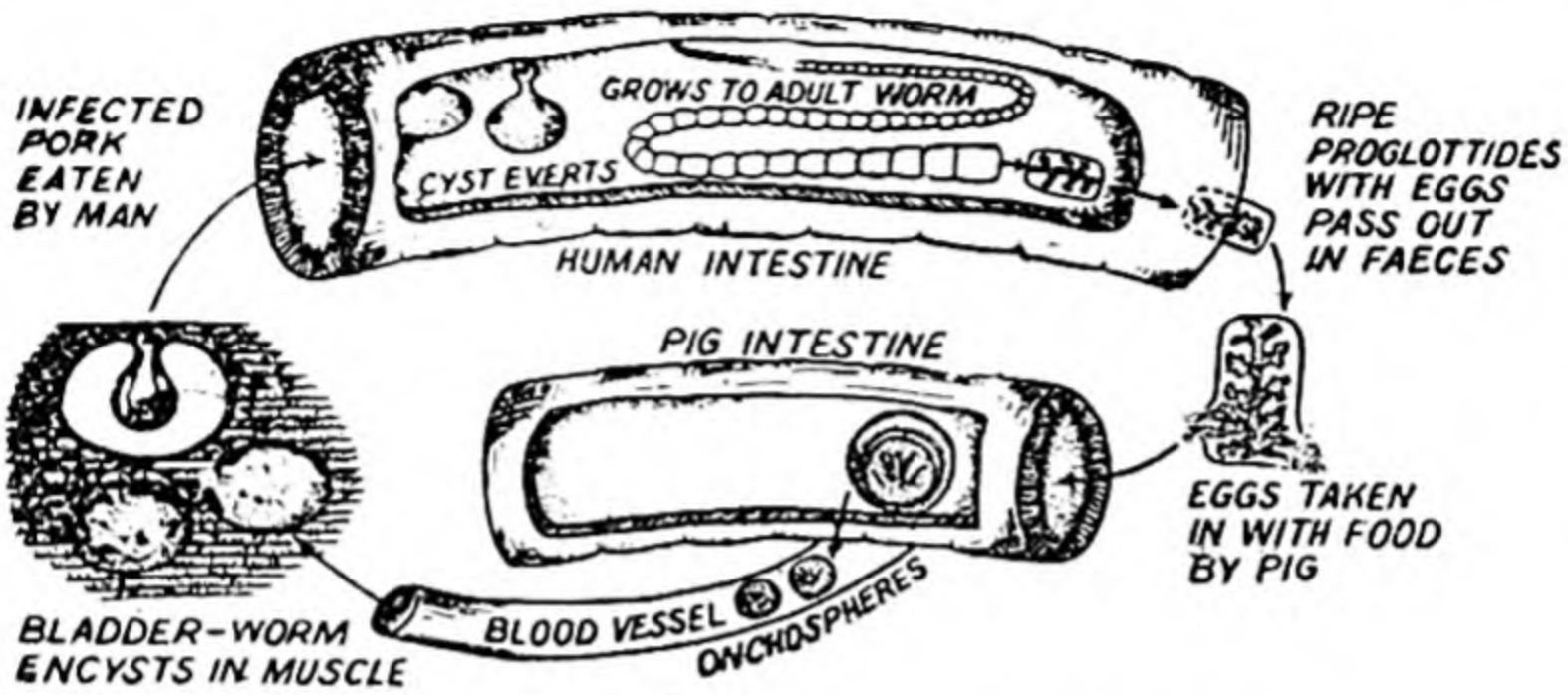

Fig. 178. Life-history of *Taenia solium* (After Storer).

right and left sides of the proglottides. There is a pair of *ovaries*, each giving off a duct. The two ducts unite to form the *oviduct* which is continued as the *vagina*. The latter opens into the genital atrium and thence to the exterior through the genital pore. There is a *yolk gland* connected with the oviduct by a short *york duct*. Just in front of the yolk gland is the *shell gland* with ducts opening into the oviduct. The *uterus* also arises from the oviduct. The junction of the oviduct, yolk duct and the uterus is known as the *ootype*. Eggs are generally self-fertilized either by sperms from the same proglottis or from one situated anteriorly. In the hinder-most proglottides the uterus becomes branched and packed with fertilized eggs while the other organs degenerate. Such ripe segments are known as *gravid* segments.

The life-history of *Taenia solium* (Fig. 178) exhibits a combination of sexual and asexual reproduction. The posterior gravid segments, containing thousands of eggs, are detached from the worm and pass out with the faeces of the host. In

the meantime a six-hooked embryo, the *onchosphere*, develops within each egg. If such eggs are swallowed by a pig, which is the second host, the onchospheres emerge from the egg shells and are carried through blood vessels to the voluntary muscles where they lose their hooks and encyst. Each cyst enlarges to an enormous size and becomes filled with a fluid. It is now called a *bladder-worm* or *cysticercus*. A part of the wall of the bladder becomes invaginated and on its inner surface four suckers and a ring of hooks appear. If insufficiently cooked pork, infected with bladder-worms, is eaten by man, the invaginated part is evaginated or turned inside out, to form the scolex of the adult. The bladder is thrown off and the scolex attaches itself to the wall of the intestine. It now buds off proglottides and gradually grows into the adult tape-worm. We thus, see that there are two main stages in the life-history of *Taenia solium*, the bladder-worm stage passed in the muscles of the pig and the tape-worm stage in the intestine of man.

Phylum Nematoda

The Nematoda are commonly known as the *round worms*. The body is long and cylindrical, and without any sign of segmentation. They include both free-living and parasitic forms. The former are found in fresh water, salt water and the soil. The alimentary canal is well-developed. The mouth lies at the anterior end of the body and the anus on the ventral surface

Fig. 179. Phylum Nematoda.

close to the posterior end. A body-cavity is present. The sexes are separate.

Ascaris lumbricoides (Fig. 179) is a common parasite in the intestine of man. The sexes are separate. The female, which is longer than the male, may attain a length of one foot. The male may be distinguished from the female by the posterior end curving sharply downwards. In the female it is more or less straight.

The body is cylindrical, yellowish white in colour, with smooth outer surface. The mouth is at the anterior end and is guarded by three lips, one dorsal and two ventro-lateral. The anus, which in the male also serves as the genital pore, is situated ventrally close to the posterior end. In the female the genital pore lies on the ventral surface about one-third of the length of the body from the anterior end.

In *Ascaris* there is no intermediate host in the life-history, the infection being direct. The eggs which are enclosed in chitinous shells, are produced in large numbers. They pass out of the intestine of the host along with the faeces. If a healthy person swallows them with food or water, he gets the infection. The eggs hatch in the intestine of the new host. The newly hatched larvae pierce the mucous membrane and enter lymphatic vessels and venous capillaries, from where they are carried to the lungs through the liver and the heart. They return to the intestine along the trachea, gullet and stomach, and grow into fully matured worms. The parasite, generally, does no harm to the host but sometimes it may cause diarrhoea, anaemia, bronchitus, etc. Santonin and thymol are used to get rid of the worms.

Phylum Annelida

The Annelida (Fig. 180) are commonly known as *segmented worms.* The body is marked externally by a series of rings or *annuli,* which ecounts for the name Annelida or Annulata. The external segmentation corresponds with an internal division of the body into similar parts. This type of segmentation is

known as *metameric segmentation*. and the segments are known as *metameres*. The body-cavity in these worms is a true coelom which is always a space between the parietal and visceral layers of the mesoderm. The circulatory system, consisting of closed vessels, is present in most cases. The nervous system typically consists of a cerebral ganglion, oesophageal connectives and a double ventral nerve-cord, bearing a series of metamerically arranged ganglia. The excretory system consists of segmentally arranged pairs of tubes, the *nephridia*. The coelom communicates with the exterior by excretory ducts. The reproductive ducts, also known as *coelomoducts*, may open to the outside independently or may unite with the excretory ducts. Development may be direct or indirect. In the indirect development there is always a free-swimming larval stage, the larva being known as a *trochophore*. The two chief classes into which the phylum Annelida is divided are Chaetopoda and Hirudinea.

Class Chaetopoda. The Chaetopoda are Annelida in which the segments are usually numerous and are clearly marked. They bear chitinous setae developed in sacs of the epidermis. Suckers are absent. The coelom is large and is divided into a series of chambers by muscular septa. The class Chaetopoda is divided into two orders, Polychaeta and Oligochaeto.

Order **Polychaeta.** The Polychaeta are mostly marine forms. There is usually a distinct head bearing eyes and tentacles. Well-developed parapodia with numerous long setae are present in most cases. A clitellum is absent. The sexes are distinct. Development is indirect, with a free-swimming larval stage.

A common representative of the order Polychaeta is *Nereis*. It is a marine form and is common in shallow waters near the sea-shore. It occurs in all parts of world It is gregarious in habit and is generally found under stones, in the crevices of rocks or among sea-weeds. It may aslo burrow in sand

It is about seven or eight centimetres in length. There is a distinct head bearing a pair of stout palps, five pairs of slender tentacles and, on its dorsal surface, two pairs of rounded eyes. Each segment, except the first and the last, is provided with a pair af muscular appendages, the *parapodia*. Each parapodium contains a large number of long setae, the parapodia are the organs of locomotion. The mouth and the anus are situated at the two ends of the body.

Order **Oligochaeta**. The oligochaeta are mostly terrestrial or fresh water forms. The head is poorly developed and does not bear any appendages. Parapodia are absent and only a small number of setae are present in the body-wall. A clitellum is usually present. The sexes are united Development is direct, without a free-swimming larval stage. This order includes the earthworms and a few aquatic forms.

Class Hirudinea. The Hirudinea are Annelida in which the body consists of a limited number of segments which are not clearly marked due to the presence of superficial secondary rings. Setae are absent. There are two *suckers*, one at each end of the body, the anterior sucker surrounding the mouth. The coelom is more or less filled with connective tissue and is represented by spaces of sinuses containing blood. This class is represented by various types of leeches.

The Medicinal Leech, *Hirudo medicinalis*, is found in fresh water ponds and streams, and is dark brown in colour. It is two to three inches in length, but is able to contract or elongate to an amazing degree. It is an *ectoparasite* or an external parasite, sucking blood from its host, which is generally a vertebrate. Due to the difficulty of frequently finding a suitable host, the crop is exceptionally large and can hold enough blood to last for a year. The leech progresses by looping movements and can also swim. On the dorsal surface, near the anterior end, there are five pairs of black dot-like eyes. There are two

suckers. The anterior sucker encloses the mouth and the posterior sucker, which is much large, is situated at the hinder

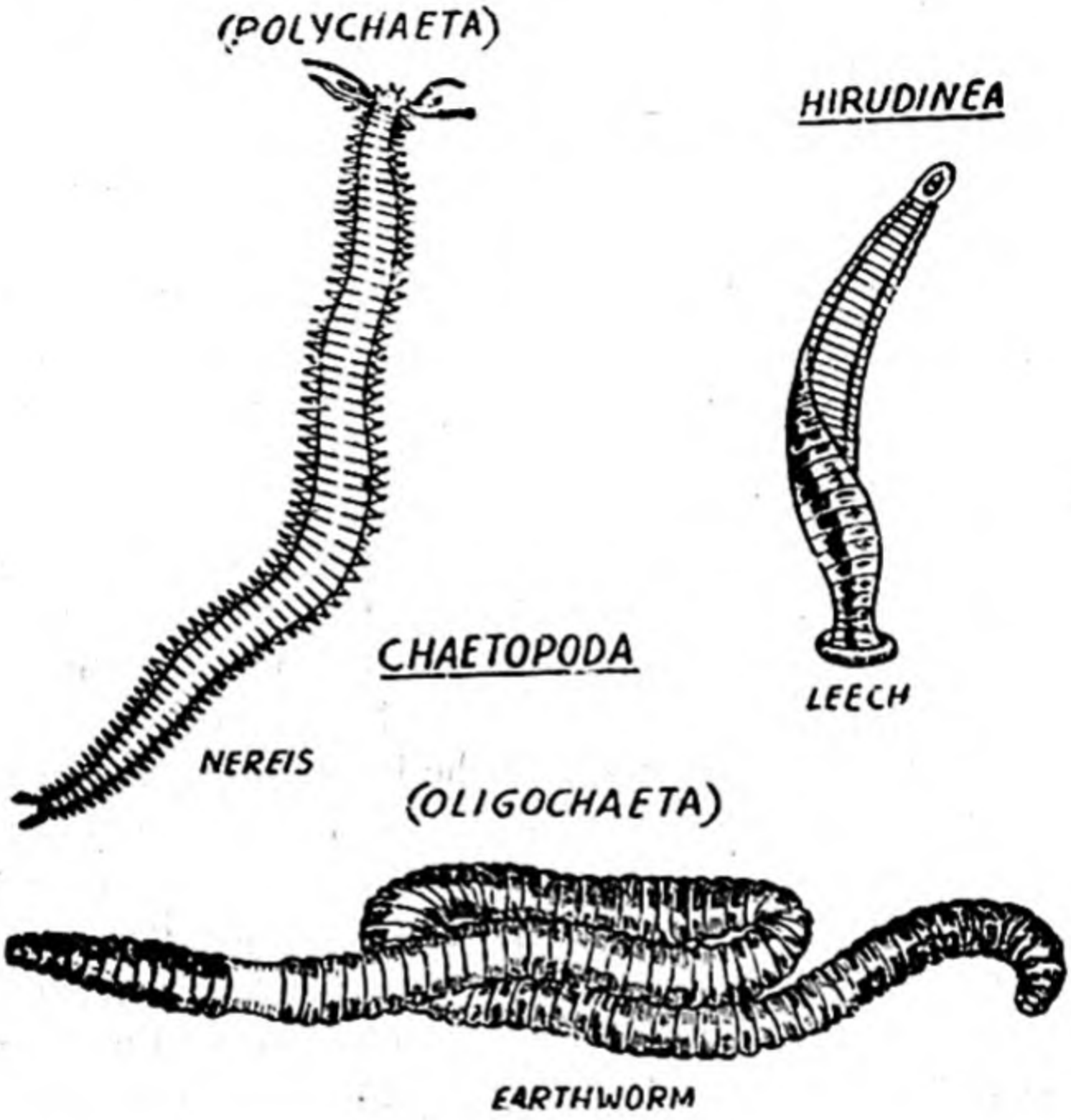

Fig. 180. Phylum Annelida.

end of the body. The suckers are organs of adhesion. The anus lies on the dorsal surface at the junction of the posterior sucker and the body.

Phylum Arthropoda

In the phylum Arthropoda the body is bilaterally symmetrical and segmented as in the Annelida. Several or all of the segments bear paired and movably jointed appendages. The

body is covered with a thick and hard exoskeleton of chitin secreted by the epidermis. Cilia, with a few exceptions, are absent. The body-cavity, which is a *haemocoele*, is much reduced and filled with blood. The phylum Arthropoda contains about four-fifths of all the known species of animals and most species have enormous numbers of individuals. They are found in all situations from the depths of the oceans to the tops of the mountains. There are aquatic, terrestrial and aerial forms. Many of them are parasites in the bodies of plants and animals. They are of great economic importance, as we shall presently see. The important classes of the phylum Arthropoda are Crustacea, Myriapoda, Insecta and Arachnida

Class Crustacea. The Crustacea (Fig. 181) include mostly aquatic animals which breathe generally by means of gills or through the general surface of the body. Some forms are terrestrial while a few are parasitic. The body is divided into head, thorax and abdomen, or the head and thorax may be fused to form a *cephalothorax*. The head bears two pairs of feelers (antennules and antennae), one pair of mandibles and two pairs of maxillae. It also bears a pair of compound eyes. The thoracic and abdominal appendages are modified in various ways for mastication, walking or swimming. They may also serve as accessory reproductive organs. The appendages are typically biramous, each consisting of a basal joint, the *protopodite*, and two branches, an inner *endopodite* and an outer *exopodite*.

The class Crustacea includes crayfishes, crabs, lobsters, prawns, barnacles, water-fleas, etc. The Crustacea are useful to man, as they provide food for him, either directly or indirectly. Most of the larger crustaceans, such as lobsters, crabs, prawns, shrimps and crayfishes, are eaten extensively in many regions of the world while the smaller kinds form a large part of the food of edible fishes.

— **Class Myriapoda.** The Myriapoda (Fig. 182) are terrestrial arthropods in which there is a distinct head bearing a pair

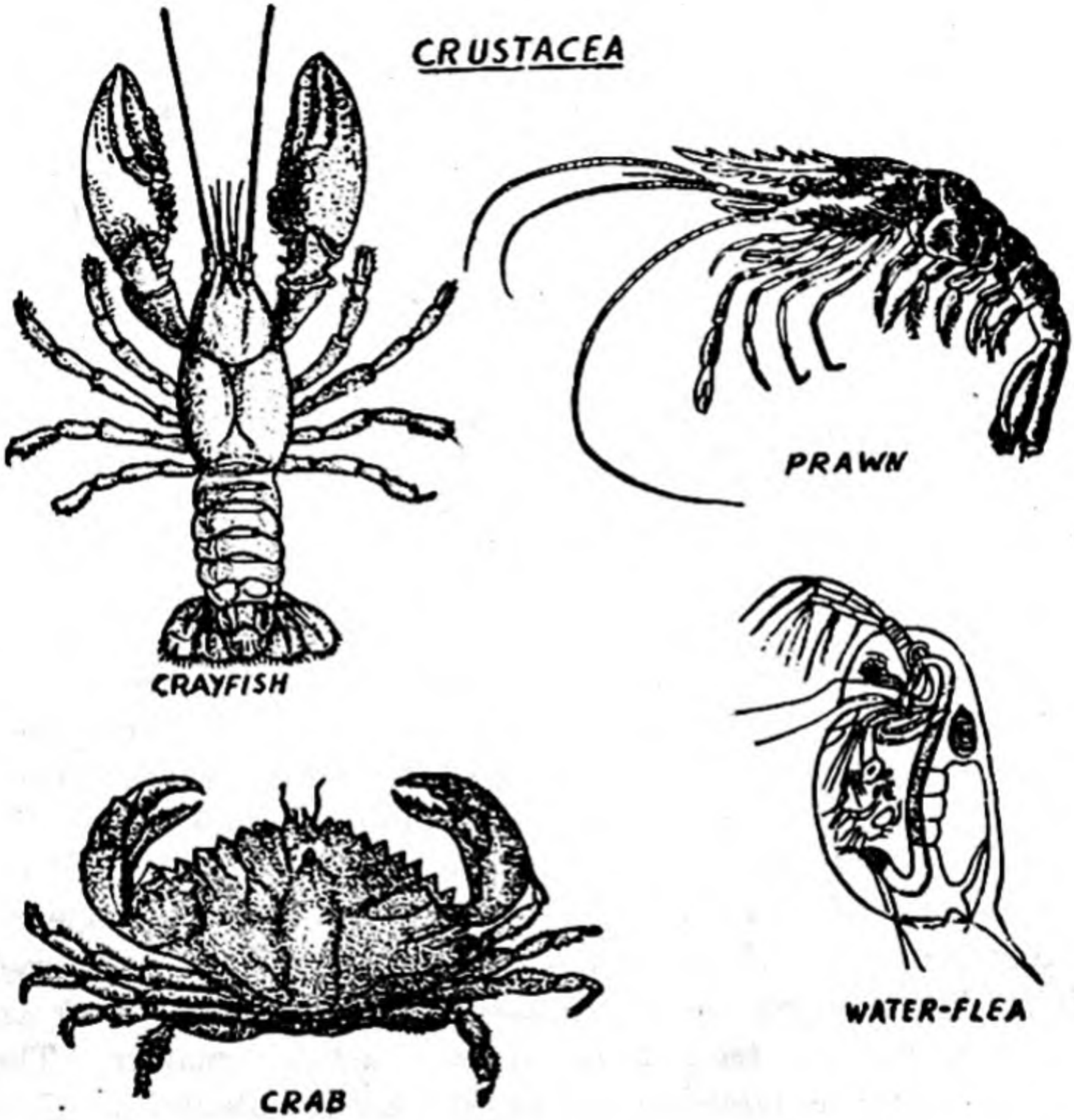

Fig. 181. Phylum Arthropoda.

of antennae, a pair of mandibles and one or two pairs of maxillae. The body consists of a number of similar segments, each bearing one or two pairs of legs. They respire, like the insects, by a system of air-tubes or tracheae. The class is represented by centipedes and millipedes.

In the centipede the body is flattened dorso-ventrally. There are two pairs of maxillae. Each segment of the body

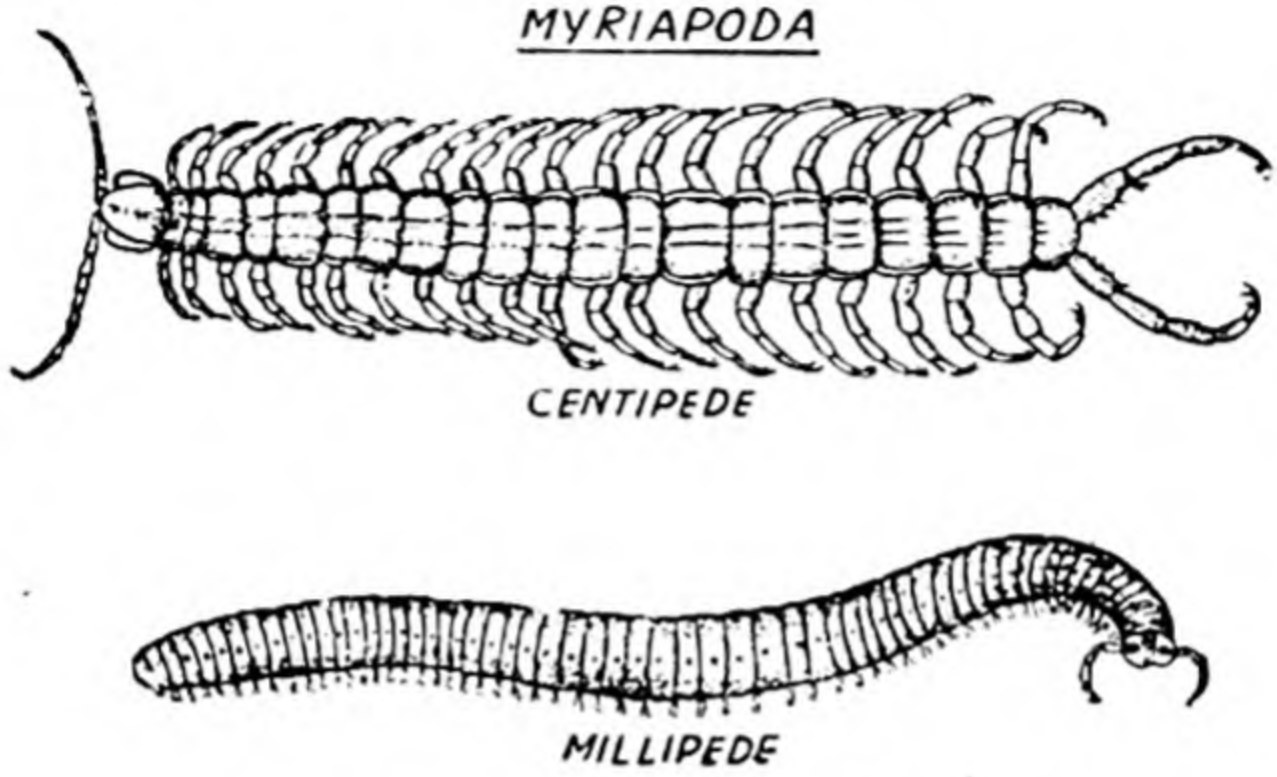

Fig. 182. Phylum Arthropoda (*continued*).

bears a single pair of legs. The first pair is modified into poison-claws which are employed to kill the prey. The centipede is nocturnal in habit. During the day it hides under stones, logs of wood, etc. *Scolopendra* is a common poisonous centipede. In the millipede the body is cylindrical. There is a single pair of maxillae. The first four segments of the body bear one pair of legs each while the rest of the segments bear two pairs each. Millipedes are gregarious in habit. They live in dark and damp places, and feed on decaying vegetable matter. They sometimes cause damage to crops and garden plants.

— **Class Insecta**. Insects constitute by far the largest single group in the animal kingdom. The total number of species so far recorded ranges between six and seven lakhs. This forms about three-fourths of all the known species of living animals.

The remarkable success that insects have achieved in the struggle for existence is mainly due to the adaptive characters which they possess for varied conditions of life They flourish

equally well on land or in water, on the plains or on the hills, in dark corners of houses or in the open sunny meadows. Indeed the present time may rightly be called the age of insects. They are the only invertebrates to possess wings which easily carry them through long distances enabling them to explore new feeding grounds and ensuring dispersal of their offspring. They multiply with amazing rapidity. This is due to the fact that most species produce large numbers of eggs and the average life-cycle of an insect is comparatively short.

The importance of insects to man, no doubt, is very great. There is a constant struggle going on between the two. The insects destroy his crops, devour his stored grains, eat up his wood-work and cause him various diseases. Some insects, however, are beneficial to him in so far as they provide him with honey and silk, and more important than that, they pollinate the flowers of most of his fruit trees and vegetable crops.

India, being a tropical country, abounds in insect-life. The loss to the country at the hands of insects is colossal. The study of insects, known as *Entomology*, therefore, is of supreme importance to us.

The members of the class Insecta (Figs. 183 and 184) are air-breathing arthropods. The body is divided into head, thorax and abdomen. There is a single pair of feelers (antennae). The thorax bears three pairs of legs and one or two pairs of wings. The abdomen is devoid of locomotory appendages. The genital opening is near the caudal end of the body. There is usually a metamorphosis in the life-history. They are found practically in all situations except in the sea. The class Insecta has been classified mainly on the basis of three characters : wings, mouth-parts and life-history. It is divided into two sub-classes, Apterygota and Pterygota.

Sub-class **Apterygota.** The Apterygota are wingless insects, the wingless condition being primitive. The mouth-

parts are sucking or chewing. Metamorphosis is absent. It includes, among others, the order Thysanura.

Order **Thysanura**. The Thysanura are small, soft-bodied insects, generally covered with scales or hair. Mouth-parts are chewing. The caudal end has a pair of jointed cerci and a median caudal appendage. A common example of the order is *Lepisma*, popularly known as silver-fish. It is about half an inch long, shining silver white, covered with scales. It is commonly found among old books, behind picture frames, under stones and heaps of dry leaves, etc.

Sub-class **Pterygota**. The Pterygota include winged insects or if without wings, the wingless condition is always an acquired one. The mouth-parts vary. Metamorphosis is of various types. The sub-class Pterygota is divided into twenty-three orders of which only the important ones would be considered here.

Order **Orthoptera**. The Orthoptera are usually stoutly-built insects. The fore-wings are thickened into *egmina* and the hind-wings, which are membranous, are folded in a fan-like manner under the tegmina. The mouth-parts are chewing. Metamorphosis is gradual. The order includes cockroaches, crickets, grasshoppers, stick and leaf-insects, etc.

The cockroach has already been studied in detail. The Ak-grasshopper has beautiful markings of blue and yellow on its body. It is found during the rainy season on the Ak plant, on the leaves of which its young ones are reared. It lays its eggs in the ground. The Desert Locust is a large and stoutly-built grasshopper. The colour of the adult is yellow with dark patches on the tegmina. This locust has permanent breeding grounds in Baluchistan, Southern Afghanistan and Persia. From these places swarms fly over Rajasthan into India. It lays 50—100 eggs in a mass in sandy places. It causes large-scale destruction of agricultural crops and its control has become a subject of national importance. The House-cricket is a

medium-sized cricket of a light brown colour. The antennae are longer than the body. It is a domestic pest and feeds on a great variety of substances. It is nocturnal in habit, The Common Praying Mantis is two to three inches long and is greenish in colour. The tegmina have a white patch, tipped with brown. It feeds on insects. It does not pursue its prey but patiently waits with front legs raised as if engaged in prayer. If an insect comes within their reach it is at once siezed by them. This order also includes the stick- and leaf-insects which resemble a twig or a leaf, thus demonstrating the phenomenon of protective resemblance.

Order **Isoptera**. This order includes the termites or white ants, which are social and polymorphic insects living in colonies composed of winged and wingless reproductive forms and numerous wingless sterile workers and soldiers. The wings are elongated and membranous. The mouth-parts are chewing. Metamorphosis is gradual

The queen sheds its wings and her abdomen becomes distended with eggs. The king is smaller in size. The worker is small with oval head. It is whitish in colour with thin and soft cuticle. It is blind. The soldier has a huge head and long scissor-like mandibles. The termites make an underground nest which projects above the ground as ant-hill and from where tunnels proceed to buildings and trees. Their chief food is wood. They attack living plants as well as wood-work in houses.

Order **Odonata**. In the Odonata the head is large and can rotate through an angle of 180°. The eyes are large and prominent. The mouth-parts are chewing. The wings are membranous and net-veined. Metamorphosis is incomplete.

The Odonata include dragon-flies and damsel-flies. In the dragon-fly the body is stoutly built, the eyes meet each other in the middle, the naiad breathes through rectal gills and

Fig. 183. Phylum **Arthropoda** (*continued*), class **Insecta.**

the wings are extended horizontally when at rest. In the damsel-fly the body is slenderly built, the eyes are widely separated, the naiad breathes by three leaf-like gills at the caudal end of the body and the wings lie flat, or stand erect back to back over the abdomen, when at rest. The dragon-flies are abundantly found over fresh water ponds and streams in which tall grasses are growing. They are fast fliers and capture the prey in flight.

Order **Homoptera**. The Homoptera, with the exception of cicadas, are mostly small insects. The wings are held sloping over the abdomen when at rest. The females of some forms are wingless. The mouth-parts are piercing-sucking. Metamorphosis is gradual.

The order Homoptera is constituted by cicadas, leaf-hoppers, aphids, mealy bugs, etc. The cicadas are large insects and are famous for their songs, but only the male can sing. Their non-stop music is a common feature of the hill-stations of India during the rainy season. The sound-producing organ is situated on the ventral side between the thorax and the abdomen. The Sugar-cane Leaf-hopper, which is about half an inch in length, is a straw-coloured insect splashed with small spots. The insects suck the juice of leaves and stems of sugar-cane plants, which are thus weakened. The Mango Leaf-hopper is about one-sixth of an inch in length. Large numbers of these hoppers are found on the mango trees throughout the hot weather, especially at the flowering season They suck the juice of the soft shoots and cause them to wither. The aphids or plant-lice are very small insects. They include some serious pests, such as the Wheat Aphis and the Cabbage Aphis. The insects cling to the plant in countless numbers. They are remarkable in giving birth to living young. The Lac Insect lives on forest trees. Lac is secreted by the insects in a semi-fluid condition which, on exposure to air, hardens and forms a protective layer over the insects crowded together on a branch.

Order **Hemiptera.** In the Hemiptera the body is often variously coloured. The fore-wings are thickened at the base with membranous distal extremities which overlap on the back, and form the *hemelytra*. Legs usually are of the running type. Metalegs are modified for swimming in aquatic forms. The mouth-parts are piercing-sucking. Metamorphosis is gradual. This order includes the true bugs. They are found on vegetation of all kinds. The nymphs are found along with their parents.

The order has a number of pests, the most important of which is the Red Cotton Bug. It measures about half an inch in length. The predominant colours are red and black. A white ring behind the head distinguishes it from another species which superfically resembles it. The Kaddu Bug, found on the Kaddu and allied plants, is reddish brown with some parts black. The aquatic bugs are found in fresh water ponds and streams. They include the water-boatmen, water-scorpions and water-skaters.

Order **Coleoptera**. The Coleoptera are minute to large insects. The body is highly chitinized. The fore-wings are veinless and thickened to form horny *elytra*, which meet in a straight line along the middle of the back. The hind-wings are membranous and are the real organs of flight. The mouth-parts are chewing. Metamorphosis is complete. The Coleoptera include the beetles of which there are 250,000 described species. This order, consequently, is the largest in the animal kingdom. It contains many pests. The Red Pumpkin Beetle has the dorsal surface orange red and the ventral surface black. It is a common pest of pumpkin, gourds, etc. The lady-bird beetles are all small beetles with hemispherical bodies. The colour is generally red or yellow with black spots. They feed on plant-lice and other small harmful insects and are, thus, beneficial to the farmer. The Hadda Beetle, a kind of lady-bird

beetle, is exceptional in being herbivorous. It is a serious pest of the brinjal plant. The grub is spiny and yellow in colour. The adult is dull reddish brown with twelve black spots. The Rice Weevil is a small snouted-beetle of a dark brown colour about one-eighth inch long. It lays eggs on rice, corn, wheat and other grains. The grubs on hatching eat into the grain and develop into adults.

Order **Lepidoptera.** The Lepidoptera are small to large insects. The wings are covered with overlapping scales. The mouth-parts are siphoning. Metamorphosis is complete. This order includes the butterflies and moths. They are the most brilliantly coloured of all insects. The butterflies can be distinguished from the moths by their knobbed antennae and a constriction bet en the thorax and the abdomen. They are day fliers while t e moths are nocturnal. There are numerous pests of cultivated plants both among the butterflies and the moths. It is always the caterpillars which cause damage to the plants.

The Cabbage Butterfly has white wings with a few black patches. The caterpillar feeds on the leaves of cabbage, cauliflower, kohl rabi, etc. The Spotted Boll Worm is a caterpillar of a moth. It feeds on ripening cotton bolls and reduces the yield. The Silk-moth, whose life history has been described earlier, yields the silk of commerce. Moths come next to bees in pollinating flowers of commercial crops.

Order **Diptera.** The Diptera are small to medium-sized insects. Only one pair of wings, the fore-wings, is present. The hind-wings are modified into small knobbed structures, known as *halters*. The mouth-parts are piercing-sucking or sponging. Metamorphosis is complete. This order includes the house-fly, mosquitoes, fruit-flies, crane-flies, etc.

The house-fly is a very dangerous insect as it carries the germs of such serious human diseases as typhoid, cholera and

dysentery from heaps of excreta, manure and filth to the human food. The transference of germs is facilitated by the presence

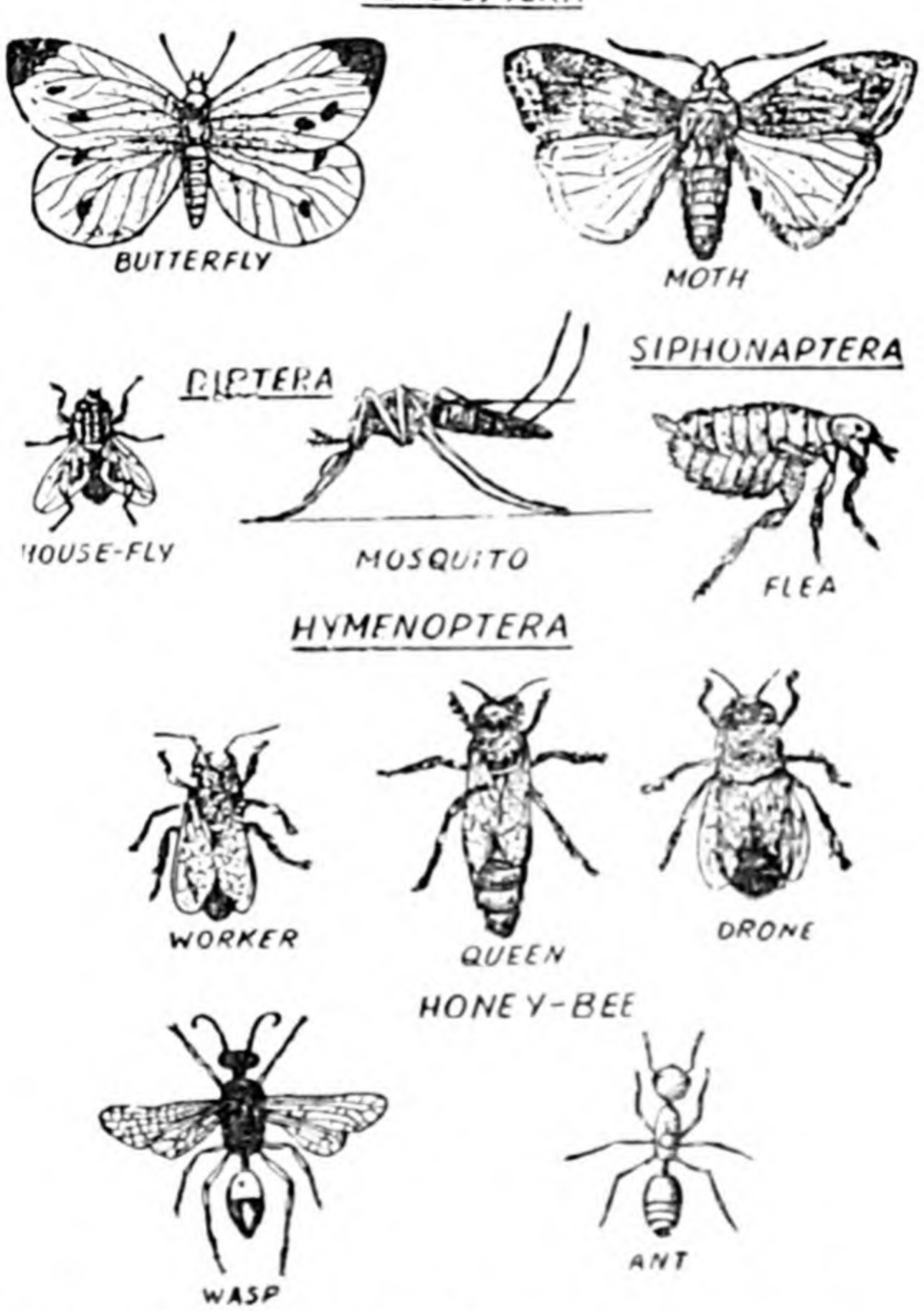

Fig. 184. Phylum **Arthropoda**, class Insecta *(continued)*

of hairs on the body and legs of the fly, and of sticky pads at the distal ends of its legs between the claws. If a healthy person eats the food, thus infected, he becomes a victim of the disease. It is, therefore, necessary to combat the fly pest. This can be done by (1) keeping the human dwellings and thoroughfares perfectly clean, (2) destroying the eggs and larvae, in the breeding places, by exposure to sunlight and by the use of chemicals, such as lime, formaldehyde, etc., (3) killing the adults by spraying insecticides like D.D.T. and benzene hexachloride, and (4) protecting the food from flies by keeping it covered, and by having fly-proof houses. Another disease-producing insect is the mosquito, as it transmits malaria, yellow fever and dengue fever. The mode of transmission of malaria by the mosquito and the measures to control malaria have already been described and so also the life-histories of the mosquito and the house-fly.

Order **Siphonaptera.** The Siphonaptera are small, ecto-parasitic, wingless insects. The body is laterally compressed. Eyes are absent. The mouth-parts are piercing-sucking. The hind-legs are adapted for leaping. Metamorphosis is complete. They are external parasites of rat, dog, goat, etc. The rat-flea transmits bubonic plague from rat to man.

Order **Hymenoptera.** The Hymenoptera are mostly social insects, living in colonies, made up of several castes, namely, workers, soldiers, king and queen. The wings are thin and membranous with only a few veins. The hind-wings are smaller than the fore-wings. The mouth-parts are chewing-lapping. Metamorphosis is complete. This order includes bees, wasps and ants.

The honey-bees are the social bees with three castes : queen, drones and workers. The workers are furnished with pollen-baskets on the hind-legs. The hive is generally attached to a tree. Here all the bees perform their specific duties. The honey-bees are of great value to man. They produce honey and

pollinate flowers. Like the bees the ants are highly social insects and have a number of castes. They have their nest under the ground where they display perfect organization, co-operation and discipline.

Class Arachnida. The Arachnida (Fig. 185) are mostly terrestrial arthropods in which the body usually consists of two regions, cephalothorax and abdomen. Antennae and true jaws are absent. The first two appendages of the cephalothorax are the *chelicerae* and *pedipalpi*, followed by four pairs of walking legs. The organs of respiration may be tracheae, or *book-lungs* which are sacs containing lamellae like the leaves of a book. The class Arachnida includes scorpions, spiders, mites, ticks, etc.

The scorpions are inhabitants of warm countries. They hide during the day-time but are active at night, when they feed on insects and spiders. The end of the abdomen bears a poison-sting which is employed to kill the small forms and to paralyse the large ones. Scorpions are viviparous. The mother sometimes carries the young on her back. In the spiders the abdomen is rounded and unsegmented. At its posterior end are three pairs of *spinnerets* which spin the thread, from which the spider's web is made. The web is employed to entangle unwary insects which form the spider's food. Many spiders do not spin any webs but capture the insects by moving about, or waiting for them in a concealed place.

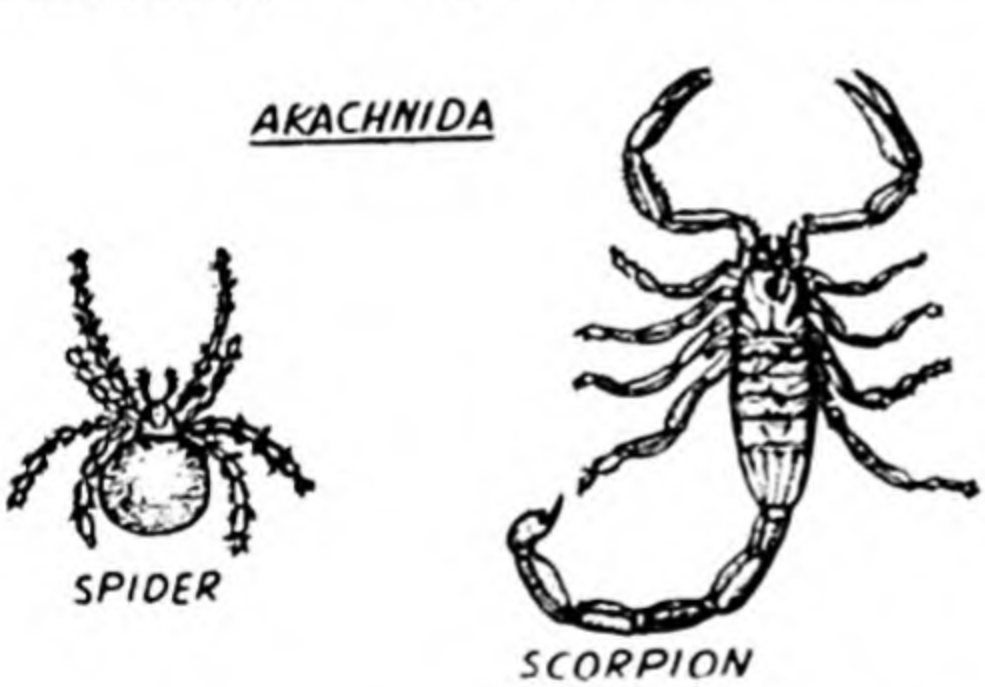

Fig. 185. Phylum Arthropoda *(continued)*.

In the mites and ticks the body is not divided into regions. The mouth-parts are chewing or piercing-sucking. The organs of respiration are tracheae. The mites are smaller than ticks. They include both free-living and parasitic forms. The mites feed on fresh or decaying organic matter and the ticks on the sap of plants or blood and soft tissues of animals. The Itch-mite causes itch in man and a related species causes mange in dogs.

The ticks which feed on the blood of higher vertebrates pierce the skin of the host and suck the blood. They are generally found in sandy regions amongst shrubs and low vegetation. Here each tick is small in size and very active. It clings to the feathers or hair of a passing bird or mammal by its legs, and pierces the skin by its sharp mouth-parts. Having thus firmly fixed itself to the host the tick sucks the blood to its utmost capacity till it swells up to more than double its original size. Now it detaches itself from the host and lets itself fall on the ground. Being distended with blood it is unable to move and lies there for many weeks without feeding. When the blood has been digested it looks for another temporary host. Various species of ticks are parasitic on poultry, cattle, dog and man. They also spread germs of certain diseases, such as tick-fever in man and Texas fever in cattle.

Phylum Mollusca

The Mollusca (Fig. 186) are soft-bodied, unsegmented, mostly sluggish animals with a fundamentally bilateral symmetry. The majority are aquatic, found both in the sea and fresh water, although a few have adapted themselves to a terrestrial life. The characteristic feature of the Mollusca is the hard *shell* which envelops the soft body. It generally consists of either one or two pieces. In rare cases it may take up an internal position or may be altogether absent. The shell

is secreted by the *mantle*, which is a fold of the body-wall and which encloses a cavity, the *mantle-cavity*. Locomotion is effected by a muscular *foot* which may take on various forms for different purposes. The Mollusca include the fresh water mussels, oysters, snails, slugs, cuttle-fishes, octopods, etc. The important classes of the phylum Mollusca are Pelecypoda, Gastropoda and Cephalopoda.

Class Pelecypoda (Lamellibranchiata). The Pelecypoda are molluscs in which the body is compressed and is bilaterally symmetrical. There is no distinct head. The mantle is bilobed and secretes a bivalved calcareous shell. The foot generally is wedge-shaped and adapted for burrowing. There is a pair of gills which are usually lamellate or plate-like. The muscular system is well-developed. The coelom is represented by the pericardium. This class includes mussels, oysters, cockles, scallops, etc.

The Fresh Water Mussel (*Anodonta*) is a common example of this class. It is found in rivers and lakes where it lies partly buried in sand at the bottom. The keel-like foot protrudes between the valves at their antero-ventral border. By means of the foot the mussel slowly ploughs its way through the sand or mud. At the posterior end there are two short tubes. The lower one, which is wider and beset with short processes, is the *inhalant siphon* and the upper one, which is narrower and smooth-edged, is the *exhalant siphon*. The respiratory current of water, which also contains food, passes in through the inhalant siphon and out through the exhalant siphon. The shells of the fresh water mussel are used for making buttons.

The Sea-mussel (*Mytilus*) is attached to a rock by means of the *byssus* which is formed by the threads secreted by the *byssus gland* situated just behind the foot. In the oyster (*Cstrea*) the right valve, which is more or less cup-shaped, is permanently fixed to a rock and the left one forms a lid over it. Two species of oysters are of economic value. The Edible Oyster (*Ostrea*

edulis) is used as food and the Pearl Oyster (*Meleagrina margaritifera*) yields pearls. If foreign body, such as a sand grain

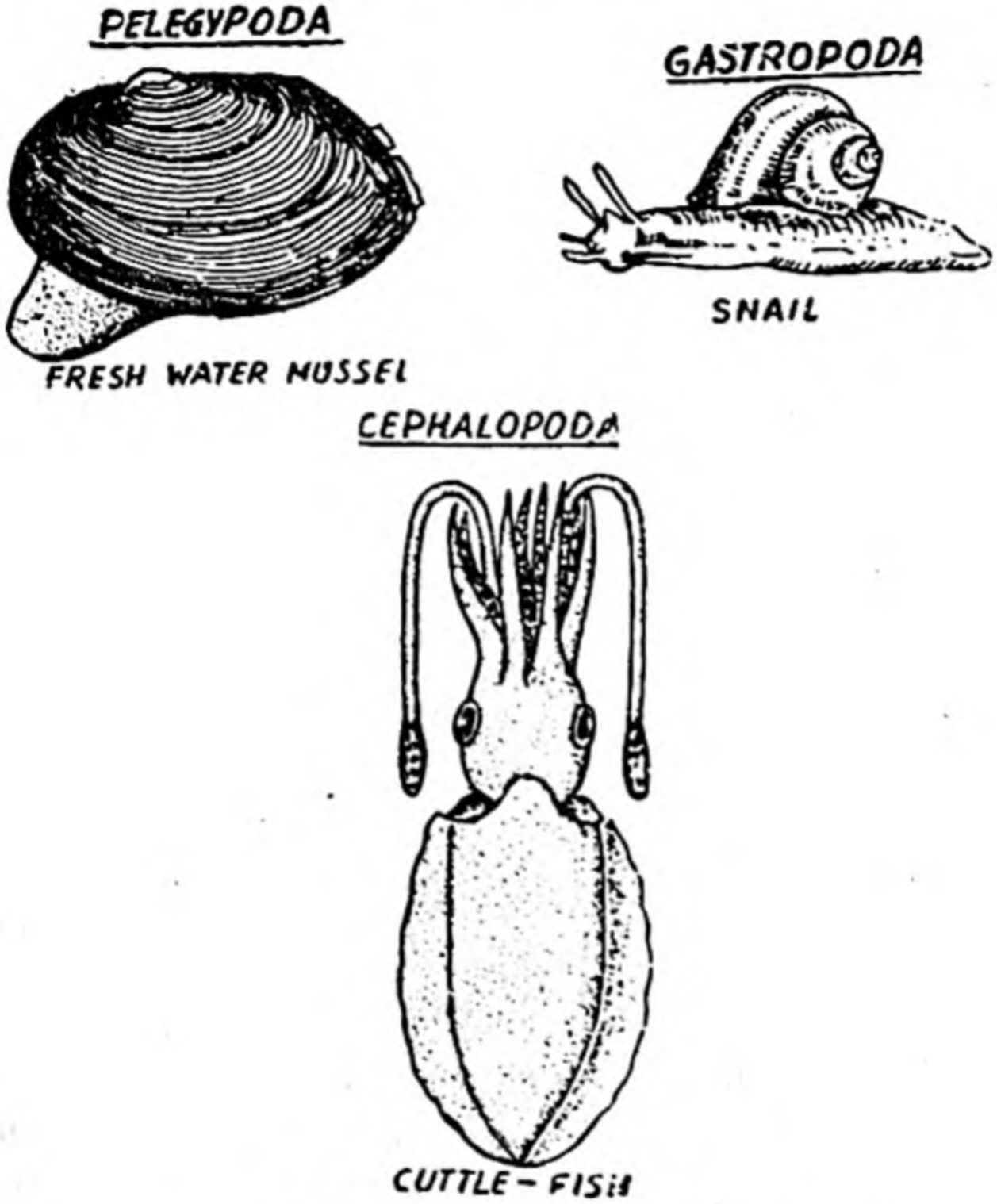

Fig. 186. Phylum Mollusca.

comes between the shell and the mantle, it forms the nucleus of a pearl. The pearly substance or *nacre*, which forms the internal lining of the shell, is secreted by the mantle round the particle to avoid irriation, till it assumes the size of a pearl. In Japan there are pearl fisheries where pearl oysters are induced to form pearls by artificially introducing foreign particles into them. The oysters, after treatment, are put into cages with perforated

walls and lowered into the sea, where they are kept for long periods, after which the pearls are removed. In the scallop (*Pecten*) the shell is ribbed and is expanded into "ear" at the apex. The animal can swim with ease by clapping the valves together. The foot, therefore, is rudimentary. The ship-worm (*Teredo*) is a burrowing form. By means of a small shell at the anterior end it bores into the bottom of wooden ships, causing considerable damage.

Class Gastropoda. The class Gastropoda includes both aquatic and land forms. The body is asymmetrical. There is a distinct head, bearing eyes and tentacles. The foot is flat and is used for creeping. The mantle is not divided into lateral lobes. The shell, when present, is single, and usually spirally coiled. There are usually two plume-shaped *ctenidia* or gills. In air-breathing forms the ctenidia may be absent, their place being taken by the mantle cavity which serves as a lung. This class includes snails, slugs, limpets, sea-hares, etc.

The Apple-snail (*Pila*) is a fresh water form usually found in ponds, lakes and paddy-fields. It feeds on aquatic plants. It has arrangement for both aquatic and aerial respiration, and can, thus, keep out of water for long periods. The shell is spirally coiled. In the extended condition the foot and the head, with the eyes and tentacles, are protruded through the opening of the shell, but at the approach of danger these parts are completely withdrawn into the shell, and the aperture closed by a calcareous plate, the *operculum*, borne on the foot. In the limpet (*Patella*) the shell is conical. The foot is broad and flat and, in addition to acting as a creeping organ, it enables the animal to adhere firmly to rock. In the sea-hare (*Aplysia*) the shell is small and internal. The foot bears two lateral extensions, the *parapodia*, which act as fins. In *Doris* the shell is absent. There is no true ctenidium, respiration being carried on by secondary branchiae which are arranged in a circle

round the anus at the posterior end. In the slug (*Limax*). which is a terrestrial form, the shell is internal. Ctenidia are absent. The mantle-cavity is modified as a lung for aerial respiration. Slugs are common in the hills during the summer months. They move so slowly that any person (or animal) who is inactive and slow-moving is called sluggish. Slugs are eaten in certain parts of Europe, but they are also harmful as they sometimes destroy small plants in greenhouses and gardens.

Class Cephalopoda. The Cephalopoda are marine and free-swimming molluscs. The body is bilaterally symmetrical. The foot is modified partly into a number of arms bearing suckers, or lobes bearing tentacles, and partly into a funnel for the exit of water from the mantle-cavity. The shell may be present or absent. When present it may be internal or external. There are either two or four ctenidia. The sexes are distinct. This class includes cuttle-fishes, squids, octopods, etc.

In the cuttle-fish (*Sepia*) the body is divided into head, neck and trunk. The head bears the arms arranged round the mouth in pairs. The arms bear suckers which serve as organs of adhesion. The fourth pair of arms, known as the tentacles, is much longer and narrower than the rest. The head bears on the sides a pair of well-developed eyes. The neck is short and the trunk is long and shield-shaped. Besides the opening of the mantle-cavity there is a large *funnel*, opening to the exterior at one end and into the mantle-cavity at the other. A current of water flows in through the main opening of the mantle-cavity and flows out through the funnel. This serves as a respiratory current besides carrying to the exterior faecal matter from the intestine and the products of the excretory and the reproductive organs. It also enables the animal to swim with darting movements in the opposite direction, that is, towards the aboral end. The shell is enclosed within the mantle and is, thus,

internal. The cuttle-fish possesses a characteristic organ, the *ink-sac*. When the animal is threatened with danger the ink is discharged from the ink-sac into the surrounding water forming a dark cloud, under cover of which it escapes. The colouring matter of the ink-sac, and the shell are used by man.

The squid (*Loligo*) resembles a cuttle-fish but has an elongated pointed body with terminal fins united aborally. In *Octopus* the body is short and rounded. There are eight arms which are connected at their bases by a web-like membrane.

Phylum Echinodermata

The Echinodermata (Fig. 187), as the name implies, are spiny-skinned animals. They include the starfishes, brittle-stars, sea-urchins, sea-cucumbers and feather-stars. They are all inhabitants of the sea. They are mostly sluggish animals and some of them (feather-stars) are permanently fixed to the bottom of the sea by a stalk. Like the Coelenterata, they exhibit a radial symmetry, the body being usually five-rayed with a central disc. In the sea-urchins, however, the body is generally spherical or disc like, and in the sea-cucumbers it is more or less cylindrical. There is a calcareous exoskeleton usually in the form of plates fitting together by their edges. In the sea-cucumbers it consists of isolated spicules. In many forms the surface of the body bears movable or immovable spines They are mainly organs of defence but in the sea-urchins they also assist in locomotion.

There is an extensive coelom. There is no definite blood-vascular or excretory system. The nervous system is well-developed. The sexes are separate. There is a free-swimming larva which has a bilateral symmetry. The radial symmetry of the adult is, therefore, only secondarily acquired.

A system peculiar to echinoderms is the *water-vascular system*. It terminates in small tubular processes of the body-wall, known

as the *tube-feet*, which can be protruded or retracted, and which have sucker-like tips. During locomotion the tube-feet are

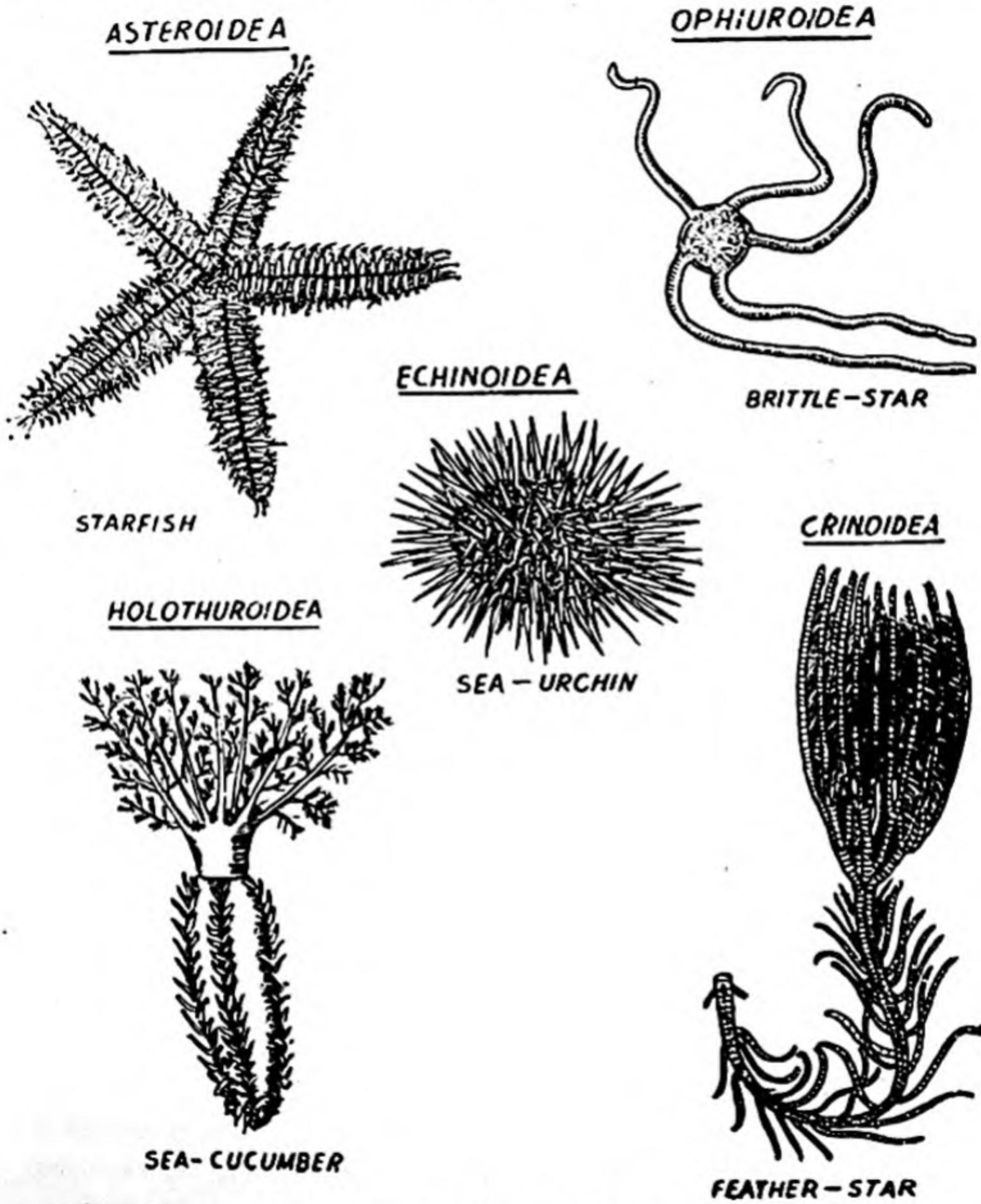

Fig. 187. Phylum Echinodermata.

extended in the direction in which the animal is moving and are

fixed to the substratum by their suckers. The tube-feet then contract drawing the body of the animal forwards. The process is repeated and thus the animal steadily moves on. The water enters the body through an opening, the *madreporite*, and is pumped into the tube-feet, where, due to varying degrees of pressure, it provides the suckers with the power by which they drag the body along.

Many echinoderms (starfishes, brittle-stars and sea-cucumbers), in face of danger, willingly cast off a part of the body and escape, leaving the broken part with the enemy. This process is known as *autotomy*, meaning self-amputation. It is a protective device. The part thus lost is *regenerated*. If a starfish is left with only a single arm and a part of the disc, it grows again into a complete specimen.

The phylum Echinodermata is divided into five classes, namely, Asteroidea (starfishes), Ophiuroidea (brittle-stars), Echinoidea (sea-urchins), Holothuroidea (sea-cucumbers) and Crinoidea (feather-stars).

Phylum Chordata

The phylum Chordata forms one of the two main divisions of the animal kingdom, the other division being the Invertebrata, and contains all the larger animals including man. The name Chordata is derived from the presence of a structure, the *notochord*, in all the members of the group at some stage of development The notochord is a rod-like structure which extends along the middle line on the dorsal side of the enteric cavity below the central nervous system. In the higher forms it becomes more or less completely replaced, in the adult, by the vertebral column.

Another character of the Chordata is the presence of a cavity, the neurocoele, in the interior of the central nervous system, which lies dorsally. The central nervous system is,

thus, hollow and dorsal, whereas in the Invertebrata it is solid and ventral.

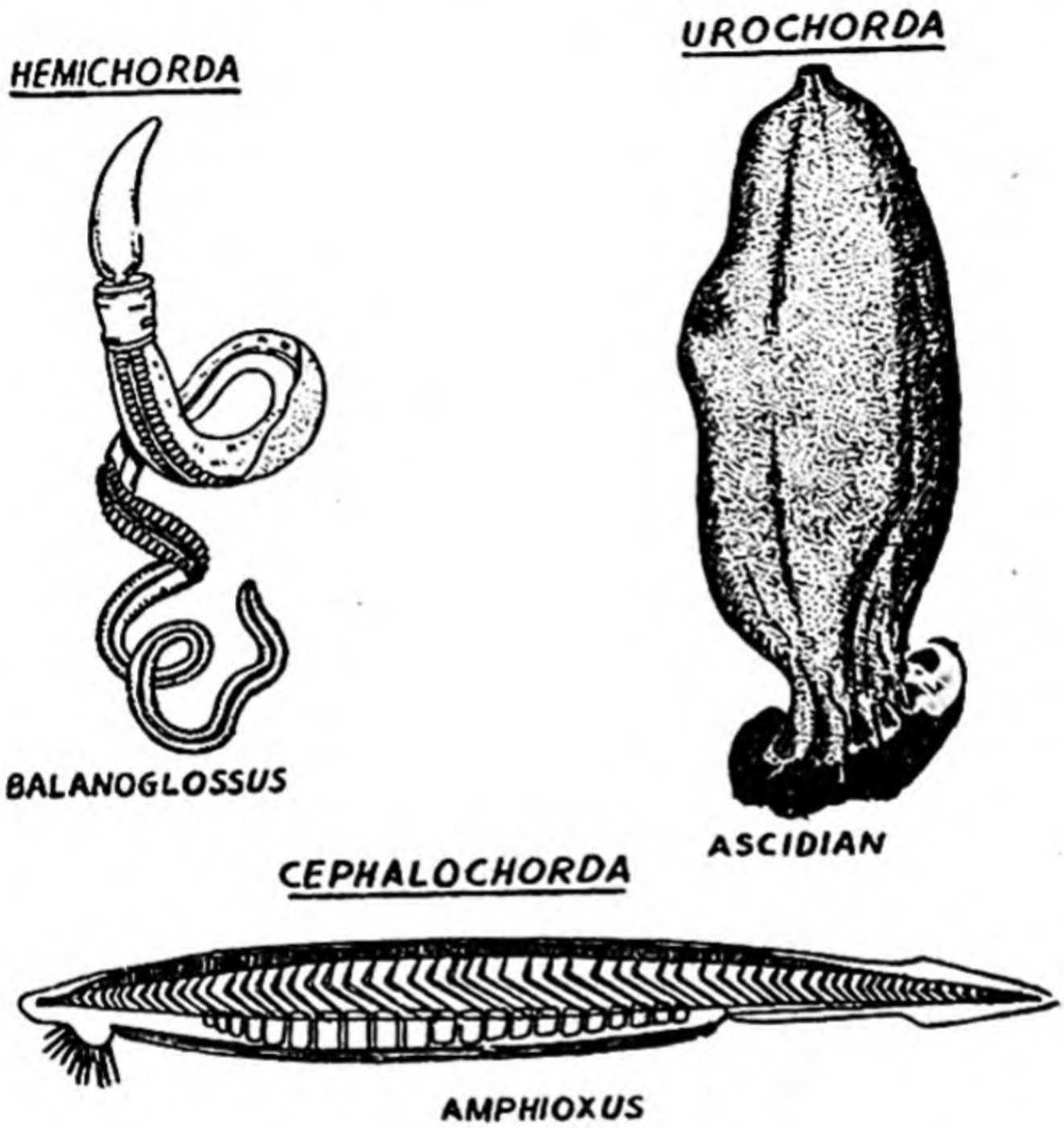

Fig. 188. Lower chordates.

The third character by which the Chordata are distinguished is that the wall of the phraynx is perforated by gill-slits, either in the embryonic or larval condition, or throughout life. In the lower chordates, fishes and some amphibians the gill-slits are retained throughout life while in all the others, that is, the rest of the amphibians, reptiles, birds and mammals, they are present only in the embryo.

The phylum Chordata is divided into four sub-phyla, three of which, namely, the Hemichorda, Urochorda and Cephalochorada, include the primitive or lower chordates (Fig. 188), while the fourth, the Craniata or Vertebrata, includes the typical chordates.

Sub-phylum Hemichorda. The Hemichorda are worm-like marine animals. They possess a notochord of doubtful homology, as it is not of the usual type but a short, rudimentary structure confined to the anterior region of the body. The most important example of the Hemichorda is *Balanoglossus*. Its body consists of three parts : the club-shaped *proboscis* at the anterior end, the belt-like *collar* encircling the base of the proboscis and the long and cylindrical *trunk*. There are two rows of gill-slits in the anterior region of the trunk. The mouth lies on the ventral surface at the base of the proboscis within the collar, and the anus at the posterior end of the body. The animal burrows in the mud by means of the conical proboscis.

Sub-phylum Urochorda. The sub-phylum Urochorda mainly includes the ascidians or sea-squirts. They are found on the sea-shore attached permanently to rocks. The body is enclosed in a tough and leathery covering, known as the *tunic*. The group, therefore, is also known as the Tunicata. There is an *oral aperture* at the free end and an *atrial aperture* on one side. A current of water enters the body through the oral aperture and leaves it through the atrial aperture. This serves both for respiration and nutrition. When disturbed, the animal throws out two jets of water through the two apertures, from which the group takes its name of sea-squirts.

In the adult ascidian the only chordate character is the presence of numerous gill-slits in the pharynx. There is, however, a free-swimming larval stage in the life-history when the animal possesses a notochord and a nerve-cord in the tail region.

But these structures disappear, along with the tail, when the larva undergoes metamorphosis and is transformed into the adult. This type of metamorphosis, in which a highly organized larva is converted into a degenerate adult, is known as *retrogressive metamorphosis*.

Sub-phylum Cephalochorda. The Cephalochorda are chordates in which the notochord is persistent throughout life and extends along the whole length of the body. A hollow dorsal nerve-cord is present above the notochord. The pharynx has numerous gill-slits. The Cephalochorda, thus, possess all the three distinctive chordate characters in the adult stage, and may be considered to lie in the direct line of evolution of the phylum Chordata.

The best-known example of the Cephalochorda is *Amphioxus*, popularly known as the lancelet, which is a marine form found in many parts of the world. It occurs near the shore and burrows in the sand. It can also swim. The body is more or less fish-like and a full-grown specimen is about two inches long. Dorsal, caudal and ventral fins are present but paired fins, characteristic of fishes, are absent. A large space, the *atrium*, surrounds the pharynx and opens to the exterior through the *atriopore*. The respiratory current of water, which also brings in food particles, passes out through the gill-slits into the atrium and thence to the outside through the atriopore.

Sub-phylum Craniata. The sub-phylum Craniata is distinguished from the lower chordates by the presence of a vertebral column. It is, therefore, also known as the Vertebrata : It is divided into two sections, the Agnatha and the Gnathostomata. The Agnatha are vertebrates without jaws. They constitute only one class, the Cyclostomata. The Gnathostomata are vertebrates with jaws. They include five classes, namely, Pisces, Amphibia, Reptilia, Aves and Mammalia.

- **Class Cyclostomata.** The Cyclostomata (Fig. 189) are eel-like aquatic vertebrates characterized by the presence of a

LAMPREY

Fig. 189. Class Cyclostomata.

suctorial mouth, devoid of jaws, but provided with horny teeth. The skin is smooth and scaleless. The skeleton is cartilaginous with a persistent notochord. Paired fins are absent. There are six to fourteen pairs of gills. There is a single median olfactory organ.

The class Cyclostomata is represented by lampreys and hag-fishes. The lampreys live in both fresh and salt waters. They attach themselves to living fishes by means of the suctorial mouth and, after lacerating the host with the sharp tongue, suck its blood and other body fluids. A common genus is *Petromyzon*. It has two dorsal fins and a caudal, but no paired fins. Behind each eye are seven small gill-slits in a row. Through them water for respiration is both taken in and passed out.

- **Class Pisces.** The Pisces (Fig. 190), including the fishes, are aquatic vertebrates. They respire by gills, which persist throughout life. The organs of locomotion are paired pectoral and pelvic *fins*, and unpaired dorsal, ventral and caudal fins. The fins are supported by fin-rays of dermal origin. A dermal exoskeleton in the form of *scales* is generally present. In most cases an *air-bladder* is present. There are no internal nostrils except in the lung-fishes. The heart has one auricle and one

ventricle. The class Pisces may be divided into three sub-classes : Elasmobranchii, Teleostomi and Dipnoi.

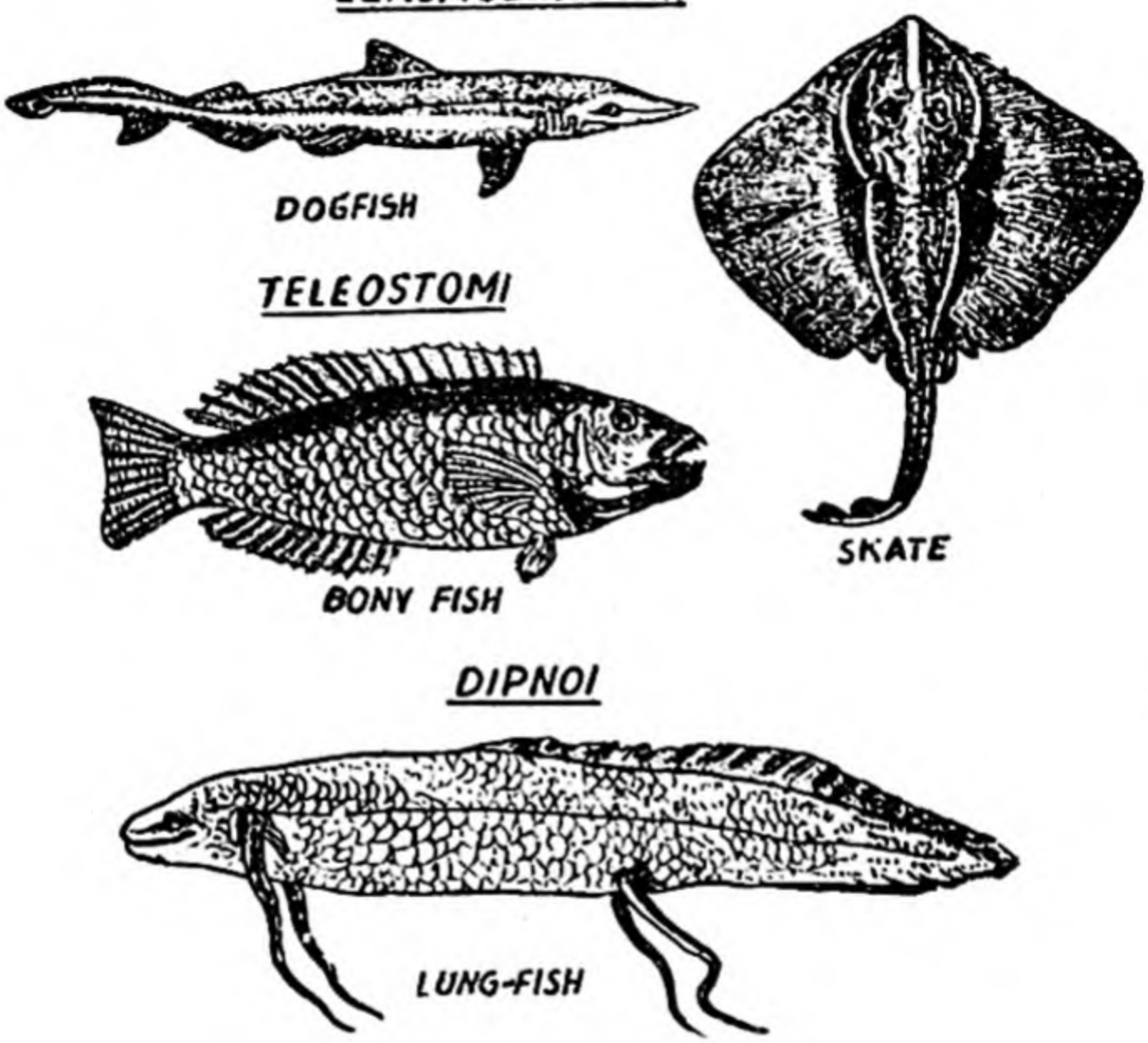

Fig. 190. Class Pisces.

Sub-class **Elasmobranchii.** The Elasmobranchii are fishes in which the skeleton consists of cartilage. They are therefore commonly known as *cartilaginous fishes*. The notochord persists throughout life. The exoskeleton consists of *placoid* (keeled) *scales* (Fig. 191). The dermal fin-rays are horny. An operculum is absent. The males are provided with *claspers*. The mouth is on the ventral side of the head. An air-bladder is

absent. The gill-filaments are attached throughout their length to the inter-branchial septa. This sub-class includes the sharks, rays and chimaeras.

Smaller sharks are known as dog-fishes, and the rays are also known as skates. In the sharks the body is fusiform and compressed laterally. The gill-slits are situated on the sides of the body. The *spiracle* lies in front of the first gill-slit. The pectoral fins are comparatively small and their anterior margins are free from the body. A ventral fin is present. They are powerful swimmers and the larger species are a terror to the fishermen. *Scoliodon* is the Common Indian Dog-fish. The skin of the shark is economically useful when it is properly treated. It is then known as "Shagreen". It is used for smoothing and polishing furniture, etc., and also for covers of handles to give them a good grip.

In the rays the body is flattened dorso-ventrally. The gill-slits are situated on the ventral surface. The spiracles lie on the dorsal surface behind the eyes. As the mouth is generally engaged in burrowing in the mud, the function of taking in the respiratory current of water is performed by the spiracles. The pectoral fins are well-developed, and are united to the sides of the body or the head. A ventral fin is absent. There are a number of interesting examples. In the Saw-fish (*Pristis*) there is a flattened and immensely elongated rostrum at the front end, bearing pointed teeth along its margins, like a saw. The rostrum may attain a length of six feet, when the fish is about twenty feet. It is used as an organ of offence and defence. In the Common Skate (*Raia*) the pectoral fins extend to the snout. In the Electric Ray (*Torpedo*) there is a pair of *electric organs* on the sides of the head. By means of these organs the ray can give powerful shocks to its enemies. Large specimens can disable a man. In the Sting Ray (*Trygon*) the tail is long and whip-like. At its junction with the body there

is a long serrated spine, at the base of which is a poison gland. The ray can inflict a severe wound by the blow of the tail.

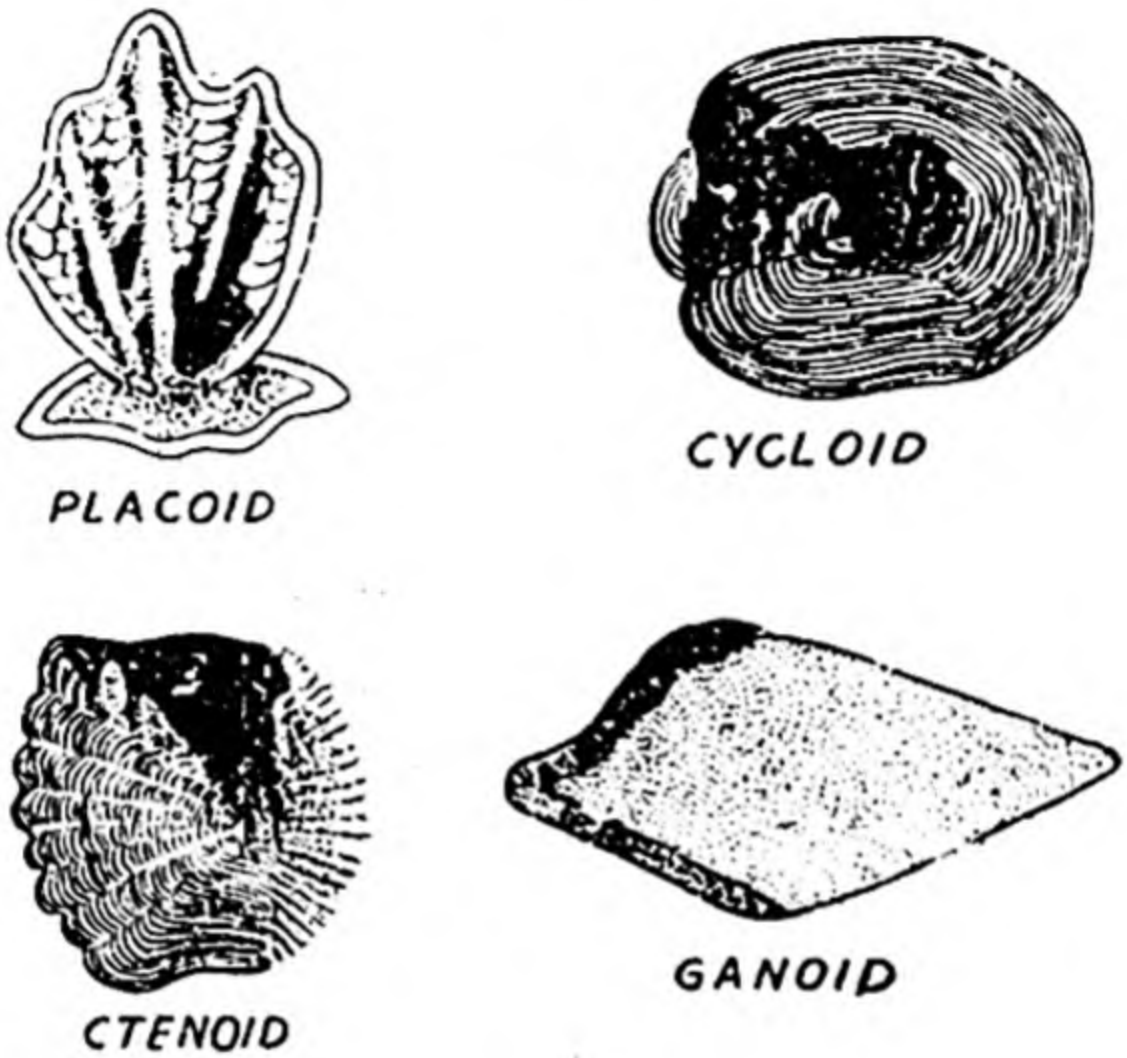

Fig. 191. Scales of fishes.

Sub-class **Teleostomi**. The Teleostomi are fishes in which the skeleton, wholly or partially, consists of bone. They are popularly known as *bony fishes*. The exoskeleton consists of bony scales (Fig. 191) which are usually *cycloid* (smooth edged) but sometimes *ctenoid* (with posterior margin toothed) or *ganoid* (covered with enamel). The fins are supported by bony fin-rays. The mouth is generally at the anterior end of the body. An operculum covers the gill-slits. A spiracle is absent. An air-bladder is usually present. The gills are filamentous and project freely from the branchial arches. This class includes

the vast majority of fishes and is perhaps the largest single group of living vertebrates. There are both marine and fresh water forms.

The body in the Spotted Eel (*Muraena*) is elongated and snake-like, with spots all over. The jaws bear sharp teeth by which the fish can inflict a strong bite. It swims by undulating movements of the body. The Sea-horse (*Hippocampus*) possesses a horse-like head. The tail is tapering and slender, and serves as a prehensile organ. The male possesses a brood pouch on the ventral side at the base of the tail. In the Flying Fish (*Exocoetus*) the pectoral fins are expanded into wing-like structures. It can glide in the air for short distances. In the Climbing Perch (*Anabas*) the operculum and some of the fins bear strong spines by means of which it can walk about on land and climb trees up to a certain height. It possesses an air-breathing chamber enabling it to live out of water for considerable periods. It is found in the fresh waters of India. In the Flat Fish (*Solea*) the body is flattened and both eyes lie on one side. It lives at the bottom of the sea, generally embedded in sand during the day and becoming active at night in search of food. In the Sucker Fish (*Echeneis*) the anterior dorsal fin on the head is transformed into an adhesive disc by means of which the fish attaches itself to floating objects or other fishes. The hold of the sucker is so strong that the fish is employed by fishermen to catch turtles. In the Fishing Frog (*Lophius*) the dorsal fin is broken up into a number of processes. The foremost process ends in a flap which is used as a bait to attract small fishes which are soon devoured. In the Globe-fish (*Tetrodon*) the body is covered with small movable spines. It can inflate the oesophagus with air like a balloon. In this condition it floats on the surface of water upside down. Its flesh is poisonous.

The bony fishes are of great value to man as they provide a

source of human food. The important food-fishes include the herring, mackeral, cod, salmon, pike, etc. Cod-liver oil,w hicn is rich in vitamins A and D, is extracted from the codfish. Certain fishes, known as larvicidal fishes, feed on mosquito larvae. They are employed to prevent the breeding of mosquitoes which transmit malaria and yellow fever.

Sub-class **Dipnoi**. The Dipnoi are fishes in which the skeleton is partly cartilaginous and partly bony. They possess, in addition to gills, a single or a double lung. They are known as *lung fishes* or *mud-fishes*. The lung is homologous to the air-bladder of the Teleostomi. The gill-slits are covered by an operculum. The nasal sacs open into the mouth-cavity by internal nares, a condition met with for the first time among fishes. The exoskeleton consists of cycloid scales. The notochord is persistent. There is no spiracle The paired fins are built on a biserial plan. The skeleton of each fin consists of a jointed central axis from which arise on the twc sides cartilaginous rays. This sub-class contains only three genera of which *Protopterus* is a true mud-fish hibernating in the dry season in mud and lying there in a coil till the next rainy season. The paired fins are long and narrow. It is found in Central Africa in marshes in the vicinity of rivers.

Class Amphibia. The Amphibia (Fig. 192). as the name implies, live both on land and in water. They are cold-blooded vertebrates with naked scaleless skin. The majority breathe by gills in the larval condition and by lungs in the adult condition, but some breathe by gills throughout life. The skeleton consists mostly of bone. The limbs, when present, are pentadactyle in structure. The heart has two auricles and one ventricle. The nasal sacs open into the mouth cavity by internal nares. There is usually a metamorphosis in the life-history. The class Amphibia includes salamanders, frogs, toads

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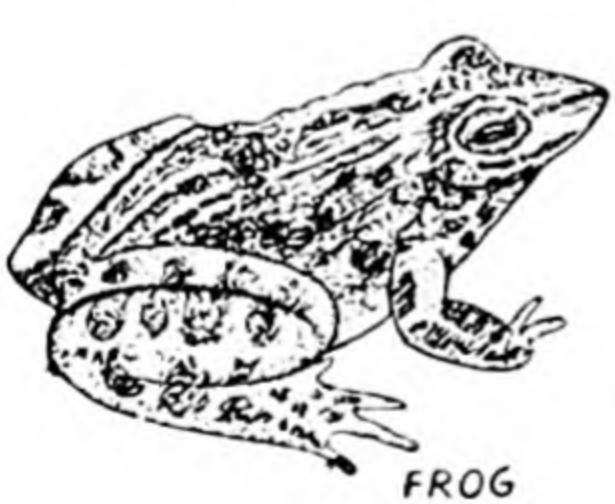
URODELA

PROTEUS

NECTURUS

SALAMANDER

ANURA



FROG

TOAD

APODA

CAECILIAN

Fig. 192. Class Amphibia.

and caecilians. It is divided into three orders : Urodela, Anura and Apoda.

Order **Urodela**. The Urodela are Amphibia in which there is a well-developed tail, and usually two pairs of limbs of approximately equal size. Gills or gill-slits may be present or absent in the adult. This order includes mud-puppies, salamanders, newts, etc.

The mud-puppy (*Necturus*) has a large size, reaching a length of more than a foot. The eyes are small but functional. There are two pairs of limbs with four fingers and four toes. There are three pairs of fringed gills and two pairs of gill-slits. It is nocturnal in habit and feeds on small frogs, worms and crustaceans. It is found in the rivers and lakes of North America. In *Proteus* the body is slender and elongated. The eyes are entirely covered by the opaque skin. There are two pairs of small and feeble limbs, with three fingers and two toes. There are three pairs of small external gills. It is confined to the subterranean waters of the caves of Austria. It lives in complete darkness and is totally blind. It feeds on small crustaceans but in captivity has been known to live without food for several years. In *Siren* the body is eel-like and the hind-limbs are absent. In *Cryptobranchus* the head and body are depressed. The tail is short with a caudal fin. There is only a single persistent gill-slit on the left side. The limbs have four fingers and five toes. It is found in the rivers of Eastern U.S.A., hiding in rock fissures. In *Amblystoma* the head is large and depressed with a wide mouth and prominent eyes. The limbs are stout with five fingers and five toes. The tail is large and without a fin. There are no gills or gill-slits. It is a land form but its larva, known as *axolotl*, lives in water. The larva is remarkable in attaining sexual maturity without changing into the adult, and breeds several times a year. This phenomenon is known as *paedogenesis*. In the salamander

(*Salamandra*) the limbs are perfectly formed with four fingers and five toes. The gills and gill-slits are absent. It is widely distributed in Europe and Western Asia.

Order **Anura**. The Anura are amphibians which have no tail in the adult. The hind-limbs are longer than the fore-limb . Gills and gill-slits are never present in the adult. This order includes frogs and toads. A toad differs from a frog in (1) being less aquatic in habit, (2) possessing a warty skin with two large swellings, the *parotoids*, behind the head, (3) having usually a rudimentary web between the toes, (4) having no teeth, and (5) laying eggs in a line and not in a mass. In the Mid-wife Toad (*Alytes*) the male winds the strings of eggs round its hind-limbs and nurses them till they are hatched. It is found in South-western Europe. In the Green Toad (*Bufo viridis*) the skin is smooth with flattened warts. The toes are webbed. The parotoids are well-developed. It can change its colour according to its surroundings. It is widely distributed and is found in the Himalayas up to a height of 5,000 feet. In the Tree Frog (*Hyla arborea*) the fingers and toes are provided with adhesive discs which enable it to climb trees. It is found in Europe, Japan and China.

Order **Apoda** (**Gymnophiona**). The Apoda are snake-like amphibians without limbs or limb-girdles. There are usually small scales embedded in the skin. The tail is absent, the anus being at the posterior end of the body. This order includes the caecilians. In *Uraetyphlus* the body is marked by ring-like grooves. The eyes are covered by the skin and are functionless. It lives in moist ground and leads a burrowing life. It occurs in West Africa and India.

Class Reptilia. The Reptilia (Fig. 193) are cold-blooded vertebrates in which the skin is covered with horny epidermal scales and in some cases with horny or bony dermal plates. The skeleton consists entirely of bone. Respiration never takes

place by gills but always by lungs. The heart has two auricles and a ventricle divided by an incomplete septum into right and left chambers. In the crocodiles. however, the septum is complete. There are two aortic arches. The class Reptilia includes the lizards, chamaeleons, snakes, tortoises, turtles, crocodiles and alligators. It is divided into three orders , Squamata, Chelonia and Crycodilia.

Order **Squamata**. The Squmata are reptiles in which the body is covered with horny epidermal scales. It contains two sub-orders, Lacertilia and Ophidia.

Sub-order **Lacertilia**. The Lacertilia are Squamata in which the limbs are usually present and are used for walking. They may also be used for clinging, climbing and digging. They may sometimes be reduced or absent, but the pectoral and pelvic girdles are, however, present. The two halves of the mandible are firmly united with each other at the symphysis. The mouth, thus, is able to open to a moderate extent only. The eyelids are, as a rule, movable and a tympanum is present. This order includes all kinds of lizards.

The geckos are small lizards, and are nocturnal in habit. The toes generally have adhesive pads by which they can run on smooth verticle surfaces. *Hemidactylus* is a common gecko or wall-lizard found throughout India. *Chamaeleon* is an arboreal form It is well-known for its power to change the colour of its skin. The toes of both fore- and hind-limbs are arranged in two groups of two and three respectively. These can be brought against each other to form a grasping organ. The tail is prehensile. The eyes are large and covered with a thick lid pierced by a small central aperture. The two eyes act independently of each other. The tongue is extended to a considerable distance when capturing an insect. It is commonly found in India. The Flying Lizard (*Draco*) has lateral wing-like expansions of the skin supported by the ribs. With

their help the animal can take short flights from branch to

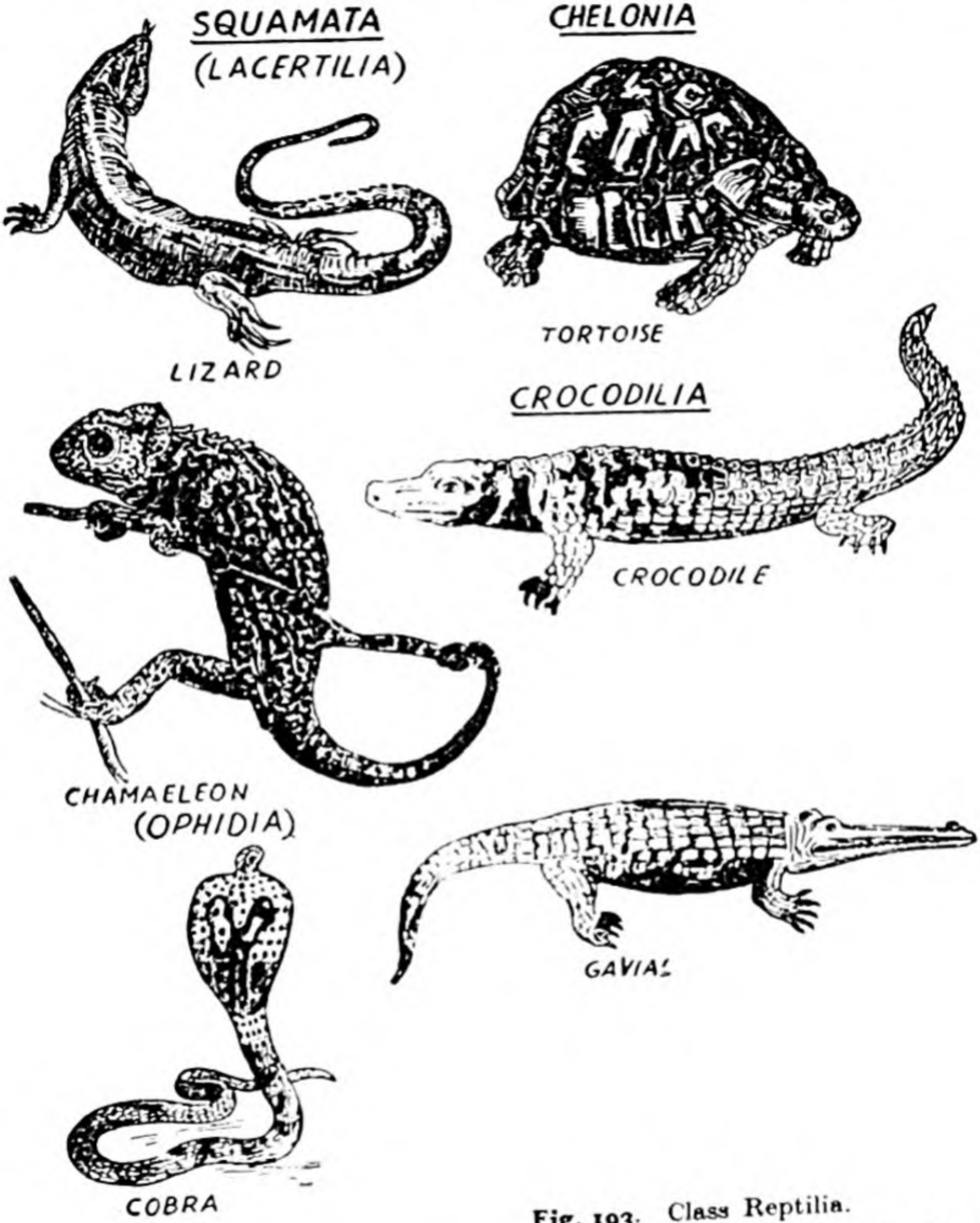


Fig. 193. Class Reptilia.

branch. *Amphisbaena* is a burrowing form. The body is

snake-like and the limbs are absent. It can walk both forwards and backwards. It is found in tropical America and Africa.

Sub-order **Ophidia.** The Ophidia or snakes are Squamata in which the body is long and narrow. It is devoid of limbs and girdles, and is adapted for crawling. In boas and pythons there are vestiges of the pelvic girdle and the hind-limbs. The two halves of the mandible are connected only by an elastic ligament at the symphysis, so that they are capable of being pulled apart. This enables the snake to swallow animals larger than the normal gape of the mouth. The eyelids are not movable. A tympanum is absent. Most of the snakes live on land, some inhabit fresh water while others are found in the sea. Of the land forms the tree-snakes live among branches of trees and the burrowing snakes under the ground. They feed on various kinds of vertebrates including fishes, frogs, lizards, snakes, birds and small mammals.

Snakes are very alert and graceful in their movements. They possess a very large number of vertebrae and each of these is provided with a pair of slender curved ribs. The snake crawls entirely by the aid of these ribs. When a part of the body has found a support on some projection of the ground, the ribs, first of one side and then of the other, in this region, are brought closer together, thereby producing alternate bends of the body on the corresponding sides. In this process the hinder portion of the body is drawn forwards and a part of it finds another support on the rough ground at the same time the anterior bent part straightens and, thus, moves forwards. It should be noted that a snake cannot move over a perfectly smooth surface. Moreover it crawls by lateral undulations of the body in a horizontal plane and not in a vertical plane as in the looping of a caterpillar. It, therefore, can move only along a wavy path and never along a straight one.

There are poisonous as well as non-poisonous snakes, but it

is not generally known that a vast majority of snakes are non-poisonous. Of the land snakes there are only three poisonous kinds which are common, namely, the kraits, vipers and cobras. The sea-snakes are all poisonous. The poison is secreted by a pair of *poison-glands* situated on the sides of the upper jaw. A duct leads from each poison-gland into a curved *fang*, which arises from the corresponding maxilla.

To tell whether a snake is poisonous the following key may be used :—

(*a*) Look at the belly. If it is covered with small scales (Fig. 194 A) or the small scales of the back are visible on the sides (Fig. 194 B) the snake is not poisonous.

(*b*) If the belly is covered with large transverse shields without small scales on the sides (Fig. 194 C) it may be harmless or poisonous, and to decide look at the top of the head.

(*c*) If the top of the head is covered with small scales (Fig. 194 D) it is poisonous and one of the *vipers*.

(*d*) If the head is covered with large shields (Fig. 194 E) it may be harmless or poisonous, to decide look at the side of the face.

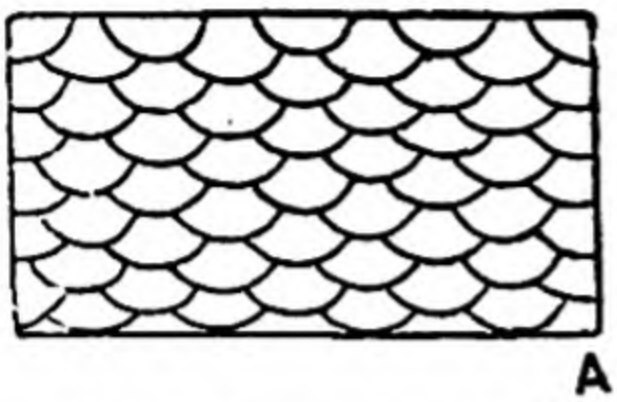
(*e*) If there is a conspicuous opening or pit between the eye and the nostril (Fig. 194 F) it is poisonous and one of the *pit vipers*.

Or

(*f*) If the third supralabial touches the eye and the nasal (Fig. 194 G) it is poisonous, being a *cobra*, *king cobra* or a *coral snake*.

(*g*) If the snake has large shields on the top of its head but has no pit between the nostril and the eye, or the third supralabial does not touch the eye and the nasal, look for the following points :—

(*h*) Middle row of scales on the back enlarged (Fig. 194 H) and only four infralabials, the fourth being the largest (Fig.



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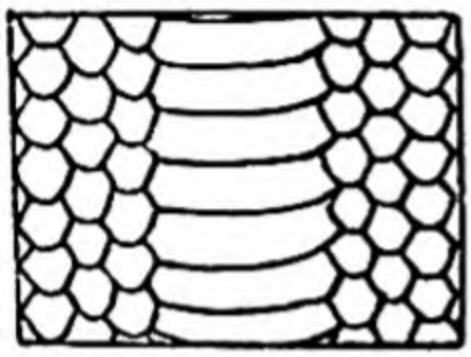

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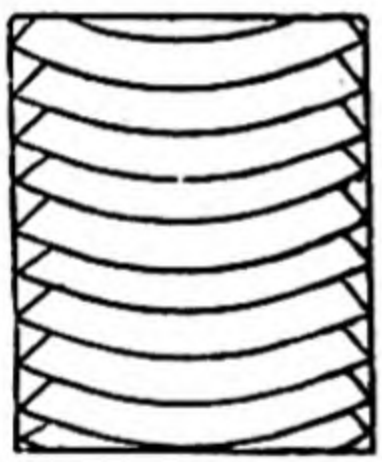

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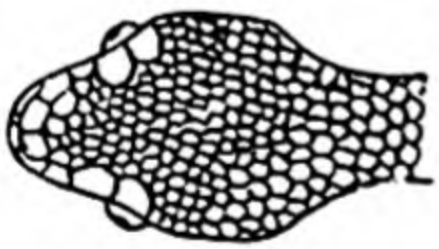

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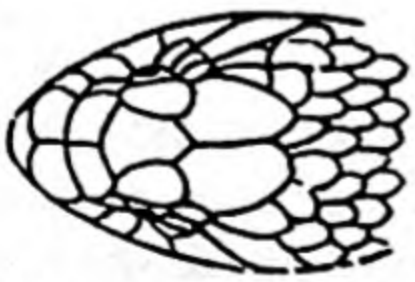

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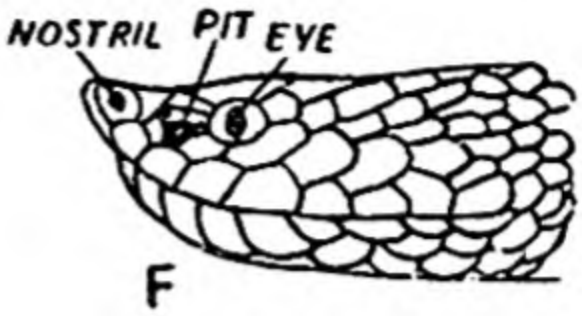

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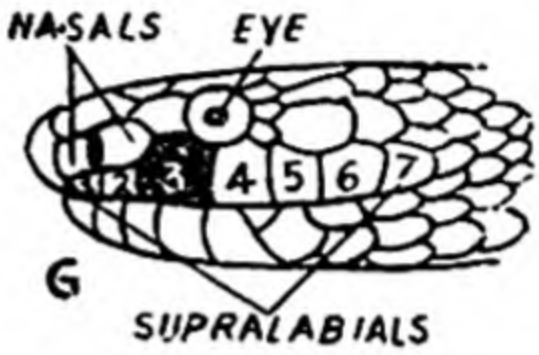

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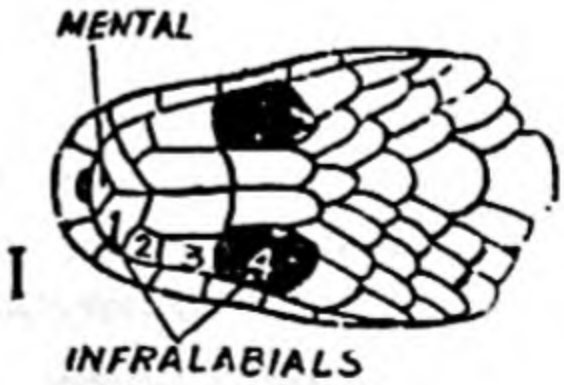

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Fig. 194. Chart of poisonous and non-poisonous snakes.
(From Prater after Wall).
(For explanation see text).

194 I). If these characters are present the snake is poisonous and is one of the *kraits*.

(*i*) If the snake has large shields on the top of its head as in Fig. 194 E, but does not possess any of the characters shown in Figs. 194 F, G, H and I, it is harmless.

(*j*) The *sea-snakes*, which may be recognized by their flattened tails, are all poisonous.

Order **Chelonia.** The Chelonia are reptiles in which the body is enclosed in a shell of bony plates, consisting of a dorsal *carapace* and a ventral *plastron*. This character alone is sufficient to distinguish this order from the others. An exoskeleton of epidermal horny plates is usually present. The limbs may be adapted for walking with clawed digits, or modified into paddles. The teeth are absent but the jaws have a horny covering. There is a single nasal opening at the front end of the snout. This order includes tortoises and turtles.

Among the tortoises there are both terrestrial and fresh water forms but none of them are marine. The carapace is more or less ovoid in shape. The head can be completely withdrawn into the shell. The limbs are adapted more or less completely for walking and are never modified into paddles. The turtles are all marine, coming to the shore only to lay eggs. The carapace is heart-shaped. The head can only be partially withdrawn into the shell. The limbs are modified into paddles.

Order **Crocodilia** The Crocodilia are lizard-like fresh water reptiles. They are the largest of the living members of the class. They have a long and powerful tail, compressed from side to side so as to aid in swimming. Under the epidermal scales on the back, and sometimes also on the belly, there are bony plates of dermal origin. The limbs are too short for the size of the animals. There are five digits in the fore-limb and four in the hind-limb. The toes of the hind-limb are more or less webbed. The teeth are confined to the jaws and are

lodged in sockets. A hard palate is present so that the internal nares are shifted backwards. The ventricle is divided by a complete septum. This order includes crocodiles, alligators and gavials. In the gavial the head has a long and narrow snout. In the crocodile and the alligator the head is short and broad but it is more so in the alligator than in the crocodile.

Class Aves. The class Aves includes the birds which are warm-blooded, bipedal vertebrates. The body is covered with feathers, a character which distinguishes birds from all other animals. The fore-limbs are modified into wings. The tail is short and bears feathers. There is a single occipital condyle in the skull. Teeth are absent but the upper and lower jaws, which form the beak, are covered with horny sheaths. The ventricle is completely divided into two, so that the heart is four-chambered. There is only a single aortic arch on the right side. They lay large eggs. The class Aves may be divided into two sub-classes, Ratitae and Carinatae.

Sub-class **Ratitae.** The Ratitae (Fig. 195) are flightless birds, usually of large size, in which the wings are greatly reduced or absent. The barbs of the feathers are free, the barbules being devoid of hooks. The sternum is without a keel. This sub-class includes ostriches, kiwis, rheas, emus and cassowaries.

The ostrich is the largest of all the living birds. It is unique among birds in having only two toes in the form. The head, neck, and legs are naked. It is found in Africa and Arabia. The cassowary has a laterally compressed beak, and a bony knob on the head. The neck is relatively short and there are three toes in the foot. It is confined to the Australian Region. The kiwi is a small bird with a long narrow beak and four toes in the foot. The wings are extremely small and the feathers are hair-like. It is found only in New Zealand.

Sub-class **Carinatae**. The Carinatae (Fig. 196) are flying birds in which the wings are fully developed and serve as

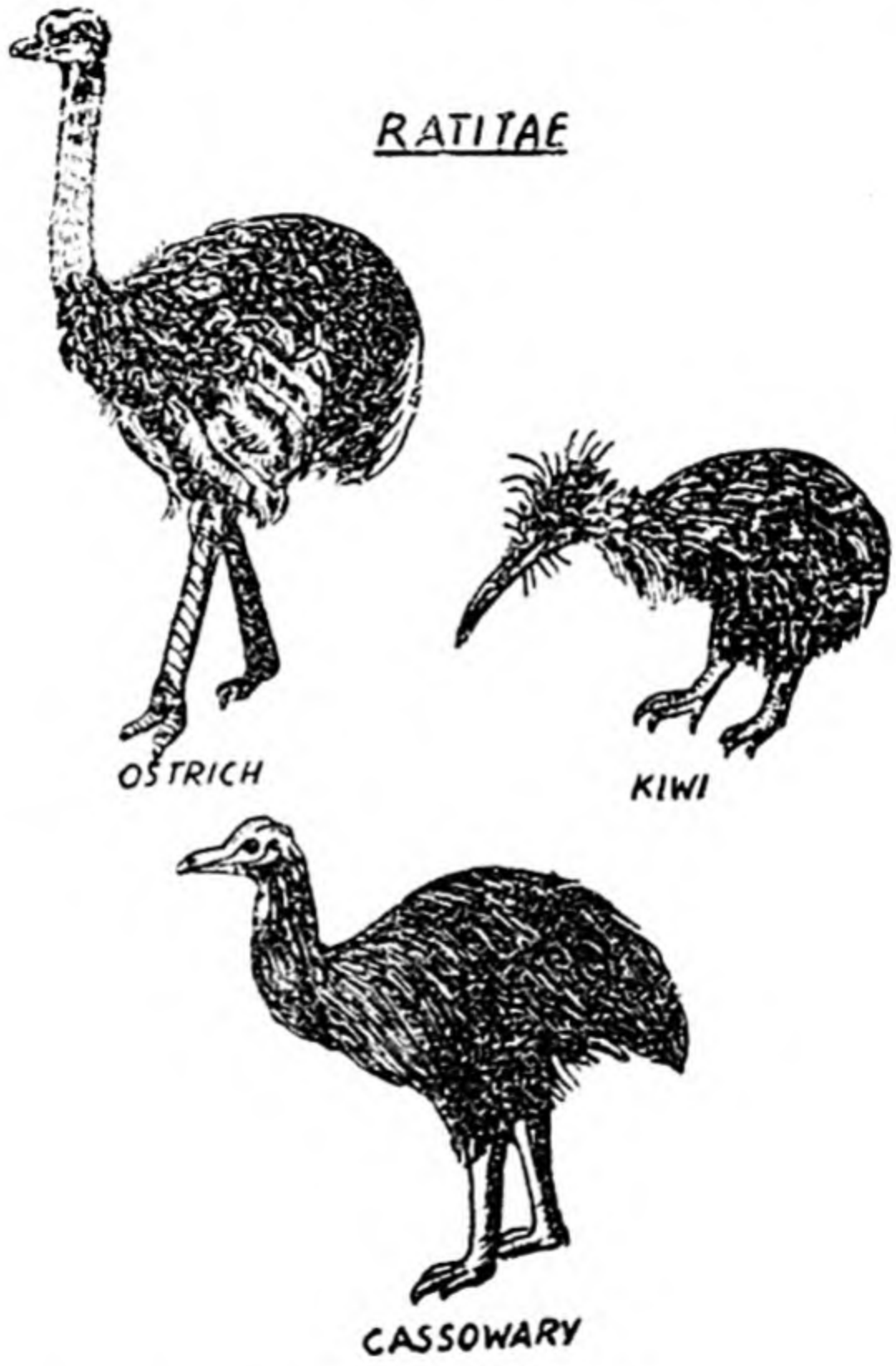

Fig. 195. Class Aves.

organs of flight. The barbules possess hooks. The sternum has a vertical median keel. This sub-class includes the vast majority of birds.

The carinate birds exhibit great diversity in their habitats and modes of life. They are generally divided into four chief groups, namely, (1) Perching Birds, (2) Birds of Prey, (3) Game Birds, and (4) Wading and Swimming Birds. The Perching Birds form a large group. They include birds which normally perch on shrubs, trees, telegraph wires, etc. They include both herbivorous and carnivorous forms. Some of them are omnivorous. The carnivorous forms feed mainly on insects and their larvae, many of which cause damage to our crops. These birds, thus, are of great value to the agriculturist. They include the king-crows, fly-catchers, blue jays, bee-eaters shrikes, etc. There are other birds, such as crows, parrakeets and bulbuls, which do great damage to agricultural crops and fruit trees. Most of the song birds, such as the Koel, Wistling Thrush and Fan-tail Flycatcher, belong to this group. The Birds of Prey are carnivorous in habit. They prey upon frogs, lizards, snakes and small birds and mammals. They are well adapted for a hunting life. They are strong fliers with remarkably sharp vision. The beak is strong, pointed and curved, and the feet bear powerful claws. They include the falcons, kites, eagles buzzards, hawks, etc. The Game Birds provide a part of man's food. They are generally weak fliers and prefer to remain on the ground where they feed on grain, seeds, berries, etc. They include fowls, quails, partridges, pheasants, etc. The Wading and Swimming Birds live near or in the water. The wading birds, such as the storks, cranes, and egrets, have long legs for wading through the water and long beaks to catch fish, crustaceans, insect larvae, etc. from the water. The swimming birds have a boat-shaped body. The beak is broad and flat for digging out the prey from the mud, and the webbed toes aid in swimming. They include teals, ducks, geese, swans etc. A few of the common birds of India are illustrated in Fig. 196.

Nest Making. Most of the birds in India breed from March to August. Before the eggs are laid the female, some-

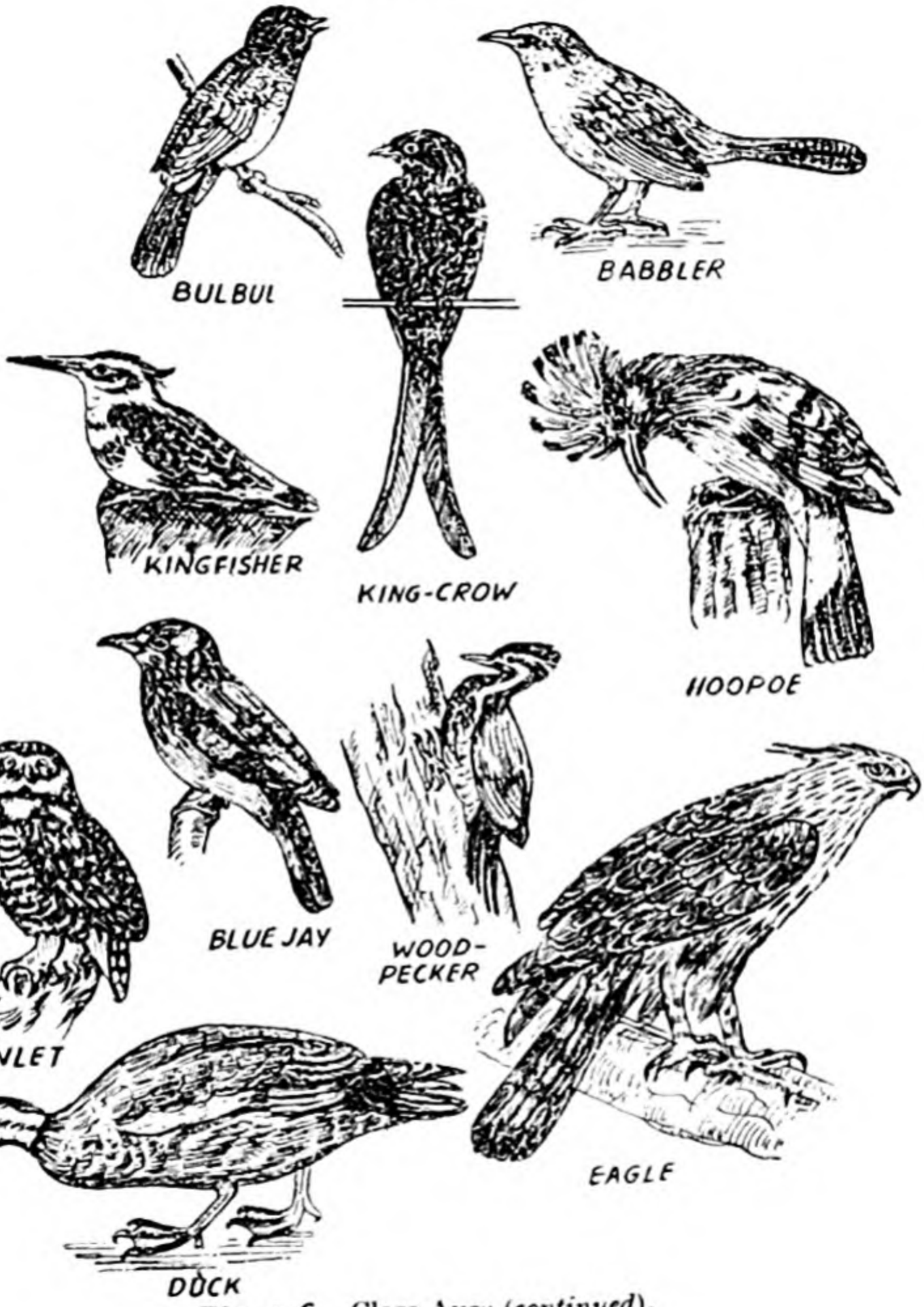

Fig. 196. Class Aves (*continued*).

times assisted by the male, constructs a nest where the eggs are to be laid and the young after hatching have to be reared. The study of the nesting habits of birds forms one of the most instructive and fascinating subjects for a naturalist. It demonstrates, in a remarkable manner, the instinct of parental care, and places the birds, apart from other considerations, on a much higher level than all the vertebrate groups we have so far studied. This instinct culminates in the mammals and is most pronounced in man.

The nests of birds are as varied in structure as in situation. Many birds, like the House-crow, build a cup-shaped nest with sticks in a fork of a tree, and line it with a soft material like grass, wool, rags, etc. The Tailor-bird, which is a small bird, is famous for its skilfully made nest which consists of two or more leaves sewn together and lined with cottonwool, small feathers, fine grasses, etc. The sewing is done by the sharp beak with cotton, silk or woollen thread. It is a common garden bird and nests can be easily located in hedges and low shrubs having tough and large leaves. The Weaver Bird or Baya is also well-known for its nest which is woven with grass stalks, leaves of maize or rice-plant, coir or coconut fibres. The nests are found in groups of about a dozen on a tree, in open country, hanging by short grass ropes. The nest is retort shaped with its mouth towards the ground. It consists of an upper egg-chamber, where eggs are laid, and a lower entrance tube. The nest is built by both the female and the male. When entering the nest the bird flies straight up into the entrance tube without perching on the outside. The Coppersmith cuts a neat round hole in the trunk of a tree. It leads into the nest-chamber by a gallery. There is no regular nest, the eggs lying on chips of wood and debris, which are already there. The Wire-tailed Swallow constructs its nest with mud. It is attached to a vertical surface of a wall or rock, generally under a bridge, close to the ceiling of a verandah or in an arch of a building.

The nest is lined with feathers. The Kingfisher excavates a long tunnel, with the egg-chamber at the end, in the bank of a stream or river. The floor of the egg-chamber is partly covered with fish-scales and debris.

Migration. The bird population of a place does not necessarily remain the same throughout the year. There are some species which stay there all the time and are known as the *resident* species, such as the House-crow, Common Mynah, Green Parrakeet, Pied Kingfisher, Peacock, Blue Jay, etc. There are others which visit the place in definite seasons eacl year and are known as *migratory* species. A bird which spends the summer, to breed, in northern latitudes is unable to find there enough food, and to bear the severity of cold, in the winter. It, therefore, moves southwards in the autumn to reach its winter quarters where food is abundant and living conditions are more favourable. At the approach of spring the return journey begins and by summer it it again at its original quarters in the north. This periodic journey with the change of seasons from the breeding place to the feeding place, or in the reverse direction, is known as *migration*. In the north the bird is called a "summer visitor" and in the south a "winter visitor," while in the regions through which it passes, it is known as a "passage migrant".

India lies in the South of Asia. In the Northern and Central Asia winter conditions are very severe. A mass of bird-life, therefore, pours into India towards the close of summer. It crosses the Himalayas and spreads over the sub-continent converging and finishing in Ceylon. In early spring the birds begin their northward journey and by the end of May cross back over the Himalayas to reach their summer homes. It is, thus, clear that all places on the migration route would have two visits from the migrants, once in each journey. Among the winter visitors to India may be mentioned the Paradise

Fly-catcher, Rose-coloured Starling, Rosefinch and some ducks, such as the Gadwall and Ruddy Sheldrake.

There are very few summer visitors to India, and even these are confined to the north-western part of the country. Moreover practically all of them migrate not from a far off country but from places further south in India. Their movements have not yet been worked out but it is probable that they migrate from the desert regions of Western India where summer heat is unbearable. The summer visitors include the Koel, Golden Oriole, Purple Sunbird, etc.

Class Mammalia. The Mammalia are warm-blooded, air-breathing vertebrates in which the body has a covering of hair. A muscular partition, the diaphragm, stretches across the body entirely separating the heart and lungs from the abdominal viscera. There are two occipital condyles. There is no distinct quadrate bone in the skull. Each half of the lower jaw consists of a single bone, the dentary. The vertebrae have epiphyses at the ends of the centra. The heart is four-chambered with complete separations of the left and the right portions. There is a single aortic arch on the left side. The red blood corpuscles are non-nucleated. The two cerebral hemispheres are connected by a broad band of nervous tissue, the corpus callosum. The external opening of the ear is guarded by a pinna. There are three distinct ossicles in the ear. The female possesses mammary glands which secrete milk for the nourishment of the young. In the male the testes have shifted backwards and lie in pouches of the body-wall, known as scrotal sacs. Excepting in the egg-laying mammals, the young are invariably born in the living condition. The class Mammalia includes the mammals. It is divided into three sub-classes, namely, Prototheria, Metatheria and Eutheria.

Sub-class **Prototheria (Monotremata)**. The Prototheria (Fig. 197) are the most primitive mammals. It is generally

believed that they have descended from reptilian ancestors as they possess many characters common with that group. There is a L-shaped episternum. The pectoral girdle has a well-developed coracoid. The testes have retained their abdominal position. There is a common opening for the gut, urinary bladder and genital duct. They lay hard-shelled eggs, and are, therefore, known as the *egg-laying mammals*. The Prototheria are, no doubt, mammals for they possess (1) mammary glands, (2) hairy covering over the body, (3) non-nucleated red blood corpuscles, (4) a diaphragm, and (5) a single left aortic arch.

The sub-class Prototheria is represented by two interesting forms, the Duck-billed Platypus or simply Duck-bill (*Ornithorhynchus*) and the Spiny Ant-eater (*Echidna*). The Duck-bill derives its name from the jaws being like a duck's bill. It is an aquatic form living in long borrows in the banks of rivers in Australia and Tasmania. The body is covered with dark brown fur. The eyes are small and the ears have no pinnae. The toes are webbed. In the fore-limb the web extends beyond the tips of the claws. This can be folded back at will to facilitate the limb being used either for digging or swimming. The food of the animal consists of crustaceans, muscles and snails. When asleep the animal rolls itself into a ball. Two eggs, enclosed in white shells, are laid at a time. The Sping Ant-eater derives its name from the covering of spines on the back, in addition to hair, and from the nature of its food which consists of ants. The legs

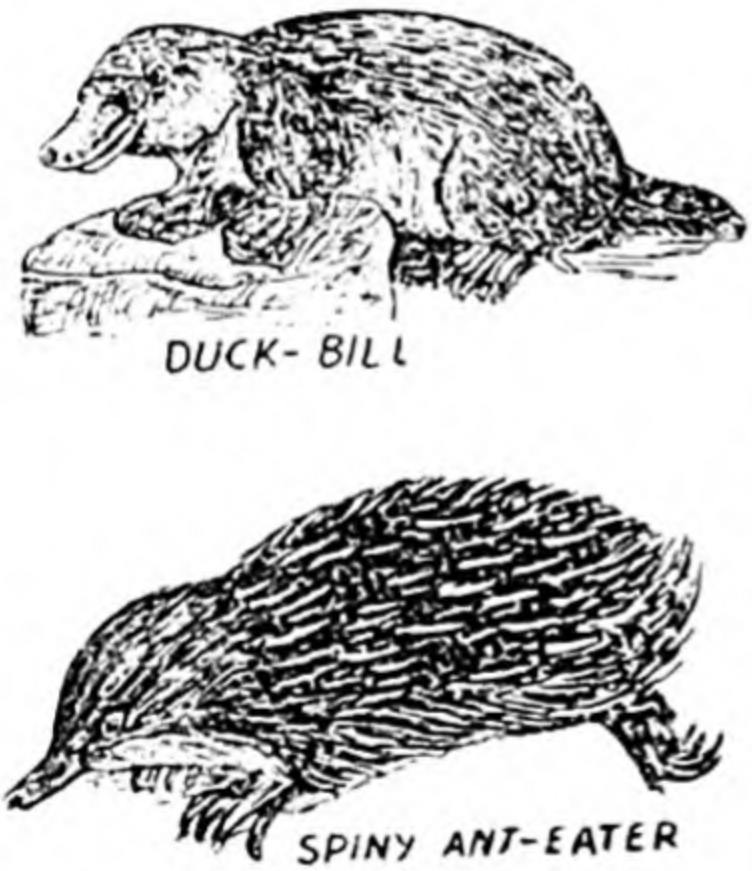

Fig. 197. Class Mammalia.

are sturdy bearing powerful claws which are employed to tear open ant hills. The fore-limbs are placed on the ground in a normal fashion but the hind-limbs have the claws directed downwards and backwards. The animal is nocturnal in habit. It feels by thrusting its long and cylindrical tongue into an ant-hill and waiting till it is covered with ants which are then swallowed.

Sub-class **Metatheria (Marsupialia)**. The Metatheria (Fig. 198) are *pouched mammals*, in which the young are born in an imperfect condition and are transferred, in most cases, into a pouch, known as the *marsupium*, on the abdomen of the mother, where they spend a considerable part of their early life. A placenta is almost always absent. The vaginae of the two sides are separate. The anus and the urinogenital aperture have a common sphincter. The brain is comparatively small and there is no corpus callosum. A pair of *epipubic* or *marsupial bones* arises from the pubis. This sub-class includes the opossums of America, and bandicoots, wombats, phalangers, kangaroos, etc. of the Australian Region.

Fig. 198. Class Mammalia (*continued*).

The kangaroo (*Macropus*) has a small head, extremely short fore-limbs and elongated and powerful hind-limbs. The tail is long and muscular. The marsupium is well-developed. When moving slowly the kangaroo progresses on all fours but

when going at a speed it takes long leaps using the hind-legs only and balancing the body with the tail which is carried horizontally behind. It is herbivorous in its diet. Although the kangaroo has the size of a man, its young one at birth is only and inch long. It is blind, naked and helpless. It has no strength to suck milk. By the contraction of certain abdominal muscles of the mother the milk is forced into its mouth. The kangaroo is found only in Australia and Tasmania.

Sub-class **Eutheria** (**Placentalia**). The Eutheria are mammals in which the placenta is highly organised. The young one is retained in the uterus for a considerable period and at the time of birth is fairly well-developed. The vagina is single. The anal and the urinogenital apertures are distinct. A corpus callosum is present. This sub-class is divided into several orders of which only the more important ones would be considered here.

Order **Rodentia**. The Rodentia (Fig. 199) are *gnawing mammals*, in which the incisors are sharp and chisel-shaped and are never more than two in the lower jaw and, in most cases, two in the upper jaw. The canines are absent so that there is wide gap or diastema between the incisors and the grinding teeth. The Rodentia are generally small animals and are herbivorous in their diet. This order includes rats, mice, hares, rabbits, squirrels, beavers, marmots, porcupines, etc.

Order **Chiroptera**. The order Chiroptera (Fig. 199) includes the bats which are the only mammals to possess the power of true flight for which their fore-limbs are specially modified. The fore-arm as well as all the digits, except the first, are greatly elongated and support the flying membrane known as the *patagium*, which is an extension of the skin. The membrane extends along the sides of the body to the hind-limbs. A similar membrane connects the hind-limbs and may include

Fig. 199. Class Mammalia *(continued)*

the tail. The first digit is small and bears a hooked claw. As a result of three modifications the bats are incapable of walking properly on the ground. They usually attach themselves to the branches of trees and hang head downwards.

There are two kinds of bats, the large bats and the small bats. The large bats are known as the flying foxes. They feed on fruits, while most of the small bats feed on insects, and a few are blood-suckers, known as *vampires*. They suck the blood of man, horses and cattle. In the small bats the sense of "touch" is so acute that they can perceive the nearness of objects without actual contact. That is why a bat that has been blinded can fly and avoid the obstacles. An example of this order is the Common Fruit-bat or Flying Fox (*Pteropus*).

Order **Cetacea.** The Cetacea (Fig. 199) are aquatic mammals in which the body is fish-like with naked skin, except a few bristles on the upper lip. The head passes directly into the trunk, there being no neck. The nasal apertures, known as spiracles, are on the top of the head. The hind-limbs are absent. The fore-limbs are modified into *flippers*. The caudal fin is horizontally flattened into two lateral lobes, known as *flukes*. There is a thick layer of fat beneath the skin, known as the *blubber*. It prevents loss of heat and lowers the specific gravity of the animal. The ear has no pinna. The eyes are small and are situated near the angle of the mouth. This order includes the whales, porpoises and dolphins.

The whales are among the largest of all known animals, whether living or extinct. An averagely large whale is about sixty feet long. The diameter of its aorta is one foot and in each beat of the heart ten to fifteen gallons of blood is pumped into the body. The whale can swim with great strength and speed. When it comes to the surface of water the air is breathed out with great force forming a column of dense cloud which goes up to a height of twelve feet. This phenomenon is known

as *blowing* or *spouting*. All whales are carnivorous. In the whale-bone whales the teeth are absent, but a *whale-bone* or *baleen*, consisting of narrow triangular plates, hangs from the palate into the mouth, to serve as a strainer. When the whale is feeding, the large mouth is opened and filled with water containing small creatures, and then closed. The tongue is now raised and the water forced out through the narrow slits in the whale-bone leaving the prey behind to be swallowed.

The whales are of great value to man as an enormous quantity of edible oil is obtained from the blubber, head region and the intestine. A single whale yields about 150 barrels of oil. Of the whales which are hunted for oil may be mentioned the Greenland Whale and the Sperm-whale. The latter also yields a substance known as *ambergris* which is used in perfumery.

Order **Proboscidea.**—The order Proboscidea (Fig. 199) includes the elephants which are the largest terrestrial mammals. They have a thick skin thinly covered with hair. The head is very large. The nose is prolonged into a long flexible *proboscis* which bears the external nostrils at its free end. The proboscis is prehensile and the animal puts it to various uses, such as conveying food to the mouth, sucking up water and pouring it into the mouth or over the body, or pulling down trees. The ears are large but the eyes are comparatively small. The tail is moderately long. The *tusks* are enormously enlarged rootless incisor teeth of the upper jaw. These are the only incisors present. The canines are absent and the grinders are transversely ridged. The elephant has a peculiar gait which is due to the fact that, while walking, it does not bend the limbs at the elbow or the knee joint. It walks on the tips of its toes but the weight of the body is carried mainly by a large fleshy cushion underneath the digits. The digits are not distinct externally but their position is marked by the presence of nails

at the points where they terminate. The number of nails may be less than the number of digits.

The elephant is an animal of the forest. It rarely breeds in captivity but can be easily domesticated. It has the reputation of being remarkably intelligent and having a good memory but these qualities appear to have been over-estimated. It is entirely herbivorous and lives on leaves and twigs of trees, grasses, shrubs, etc. It is particularly fond of water and is a good swimmer. Its age has been estimated to be between 100 and 150 years. The domesticated elephant is largely employed as a beast of burden, particularly for dragging timber to the rivers. Ivory is obtained from its tusks. There are only two species of living elephants found respectively in India and Africa. In the Indian Elephant (*Elephas indicus*) the female has no tusks whereas in the African Elephant (*Elephas africanus*) tusks are present in both sexes.

Order **Ungulata.** The order Ungulata (Fig. 200) is a large and important group. It includes the *hoofed mammals.* They are terrestrial and herbivorous animals and their limbs are adapted for running. The toes instead of bearing claws or nails, as in most other mammals, are enclosed in solid hoofs. They, thus, walk on the tips of their toes. The first digit in both limbs is always absent. There are no clavicles. The order Ungulata is divided into two sub-orders, Perissodactyla and Artiodactyla.

Sub-order **Perissodactyla**. The Perissodactyla are ungulates in which the horns are absent. The axis of the limbs passes through the third digit, which is larger than the others. The toes of the hind-limb are odd in number and are never more than three. The stomach is simple and the caecum is large. The gall-bladder is absent. This sub-order includes the tapirs, horses, asses zebras and rhinoceroses.

The tapirs are found in the tropical region, in marshy places

close to water. They are nocturnal in habit and are inoffensive by nature. They are found in Malaya, Java and South America. The horses, along with the asses and zebras, are the most highly evolved of the perissodactyla. They all possess a single hoof which represents the third digit. The second and fourth digits are reduced to *splint bones* while the first and the fifth are absent. The horse (*Equus*) has ceased to exist in the wild state, although it is believed that there is a wild horse in Siberia. The incisors of the horse are chisel-shaped and each has a pit by which the age of the animal can be determined. The pits are absent in old age. In the horse the tail has long hair arising from its root whereas in the ass they arise from the middle part and from near its tip. The rhinoceros is a large and unwieldy animal. Its height is about five feet and length about ten feet. The skin is thick and tough, and is thrown into folds. The animal, as a rule, is not offensive but when attacked shows great fury and anger. The One-horned Rhinoceros (*Rhinoceros unicornis*) is an Indian species. It is at present found at the foot-hills of Nepal as well as in Orissa and Central India, but in historical times it was probably found all over Northern India. There is a record of Babar having killed a rhinoceros in Peshawar. The two-horned Rhinoceros (*Rhinoceros bicornis*) is met with in Africa.

Sub-order **Artiodactyla.** The Artiodactyla are ungulates in which true horns are usually present. The axis of the limbs passes between the third and fourth digits, which are equally developed. The stomach is generally complicated and the caecum is small. A gall-bladder is usually present. This sub-order includes pigs, goats, sheep, hippopotami, deer, antelopes, oxen, camels, giraffes, etc.

The Artiodactyla are divided into two chief types, *non-ruminants*, including the pig and hippopotamus, and *ruminants*, including all the remaining animals. As the name indicates the ruminants *ruminate* or chew the cud, that is bring back

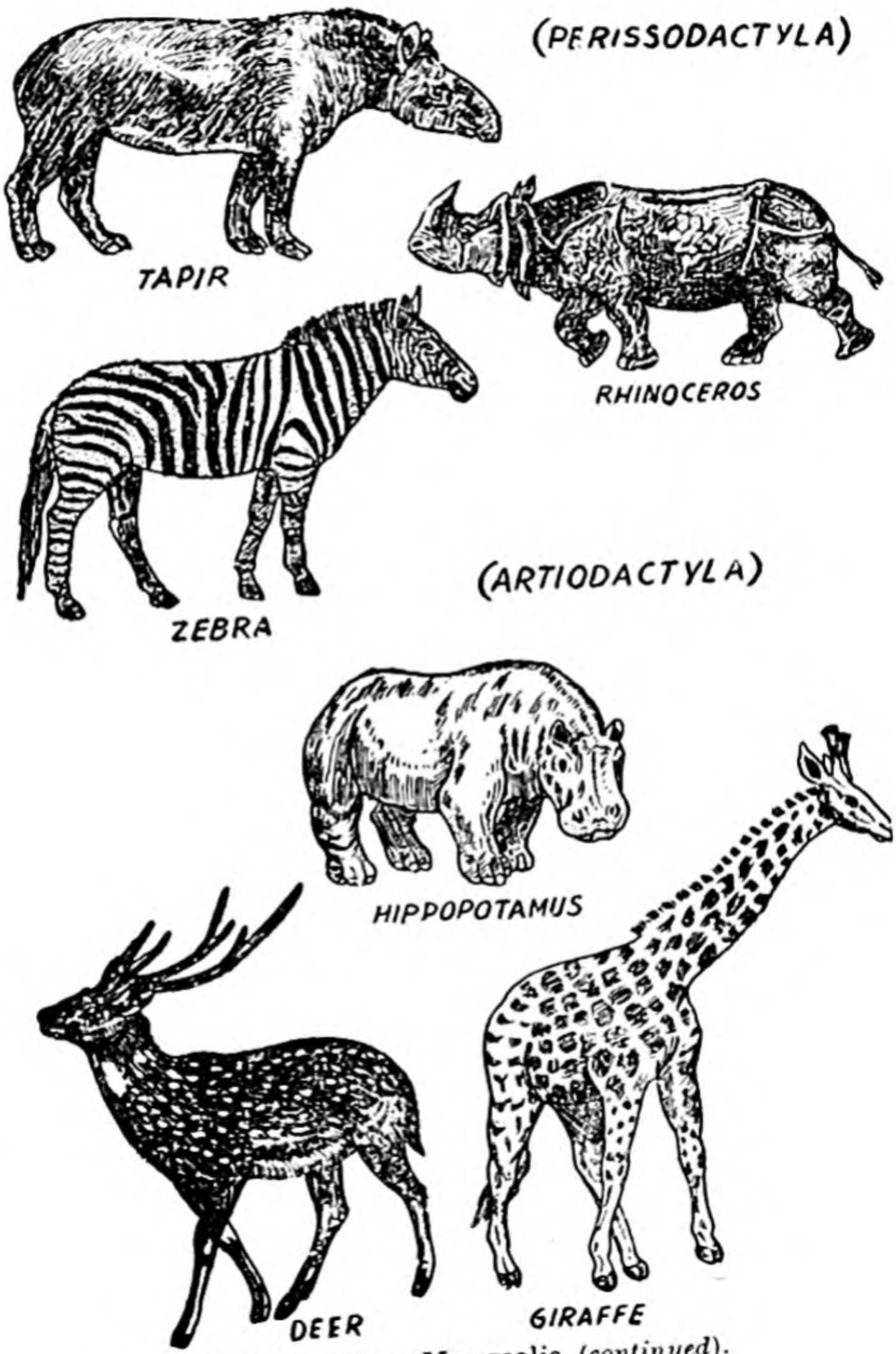

Fig. 200 Class Mammalia *(continued)*.

from the stomach half digested food into the mouth for further chewing. The stomach is generally divided into four chambers. In the pig the canines are enlarged to form tusks which serve as organs of offence and defence. The hippopotamus is a large animal, found on the banks of rivers. It is confined to Africa. In the deers the horns are called *antlers*. They consist entirely of bone and are branched. They are shed every year, and new ones are formed. They are present only in the male except in the reindeer in which both the sexes bear them. In the oxen and the allied forms the horns are of a different nature from the antlers. They consist of a bony core covered with the horn proper. The horns are epidermal in origin. They continue growing throughout the life of the animal and are nots hed. They are never branched. The camels (*Camelus*) are harmless animals. The stomach has three chambers. From one of them a large number of diverticula are given off, each with a sphincter muscle. These are called *water-cells*. They store water which enables the animal to withstand long periods of draught. The Arabian camel is single-humped while the Turkish camel is double-humped. Lamas are like camels but are smaller in size. They are found in South America and are without a hump. They are covered with thick fur which is very woolly and fine garments are made from it.

Of all the groups of mammals, or perhaps of the animal kingdom, the ungulates are of the greatest benefit to man The sheep, goat and pig provide us with meat, and the cow and buffalo with milk. The horse is used as a means of transport and the ass as a beast of burden. The camel carries men and goods across the deserts. The ox comes to our aid in agricultural operations. The sheep is the main source of wool, and other animals of leather. Even their bones are crushed and used as manure, as also their dung. Deer-hunting is a popular sport. The antlers of deers decorate our walls. Musk is obtained from the Musk-deer of Central and Eastern Asia.

They are all gentle creatures, and constant companions of man.

Order **Carnivora**. The order Carnivora (Fig. 201) includes the dogs, jackals, wolves, foxes, cats, tigers, lions, leopards, bears, etc., and their aquatic allies, the seals and walruses. As the name implies, the Carnivora are mostly *flesh-eating mammals*. The incisors are small but the canines are large and projecting. There are usually five digits in the limbs but never less than four. The digits are provided with sharp claws which may be retractile. This order is divided into two sub-orders, Fissipedia and Pinnipedia.

Sub-order **Fissipedia**.—The Fissipedia are terrestrial carnivores in which the last premolar in the upper jaw and the first molar in the lower jaw are so modified as to work against each other like a pair of scissors. They are used for cutting the flesh and are known as the *carnassial teeth*. The toes are separate. It includes all the land forms. The cats tigers, lions and leopards belong to the genus *Felis*, the dog and its allies, such as jackals and wolves, to the genus *Canis*, and the bears to the genus *Ursus*. In the cats the claws are completely retractile while in the dogs and bears they are non-retractile. The cats and dogs walk on their toes and are carnivorous while the bears walk on the soles of their feet, and are omnivorous, feeding on flesh, fruits, honey, etc.

Sub-order **Pinnipedia**. The Pinnipedia are aquatic carnivores with pentadactyle paddle-shaped limbs, the digits being united by a fold of the skin. The nails are generally small or absent. The tail is short. The carnassial teeth are absent. They mainly live in the sea but breed on land. They move on land in a very clumsy manner. This sub-order includes seals and walruses.

In contrast to the ungulates, the carnivores are ferocious animals. Many of them, like the tiger, lion and leopard cause loss of human life, although some, like the dog and cat can be

CARNIVORA

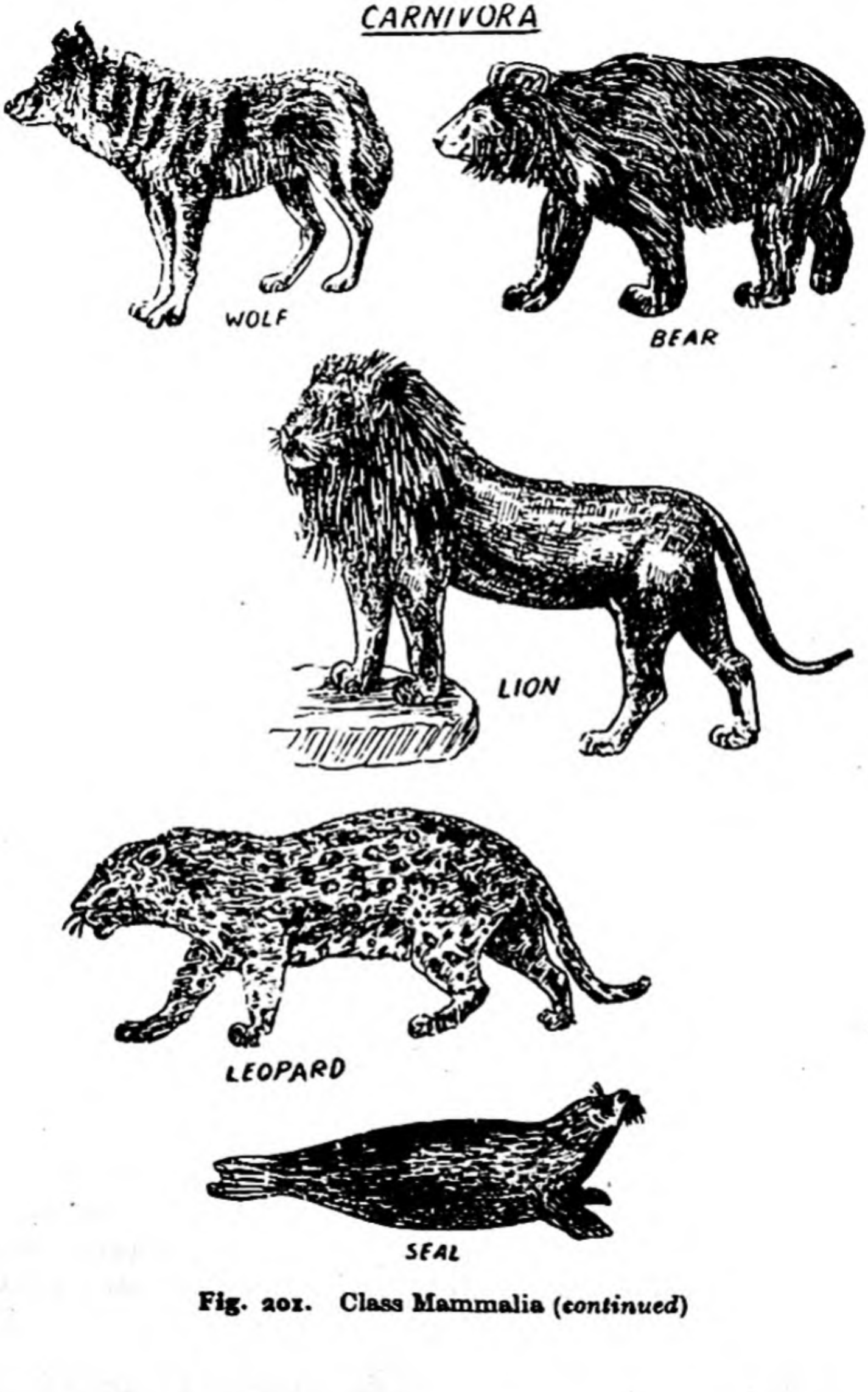

Fig. 201. Class Mammalia (*continued*)

easily domesticated. The dog is well-known for its loyalty and faithfulness to its master.

Order **Primates.** The order Primates (Fig. 202) includes the lemurs, monkeys, apes and man. They are mostly *arboreal mammals.* Their food consists chiefly of fruits and seeds, but also insects, eggs and birds. They walk on the soles of their feet. The thumb and the great toe can be brought against the other digits to form grasping organs. The tail, when present, is generally prehensile. The orbits of the eyes are turned forwards and, except in the lemurs, are enclosed completely by bone. The digits have flat nails. The cerebrum is large and generally covers the cerebellum. There are two mammae on the thorax. The female, as a rule, produces only one young at a time, and nurses it with great care and affection.

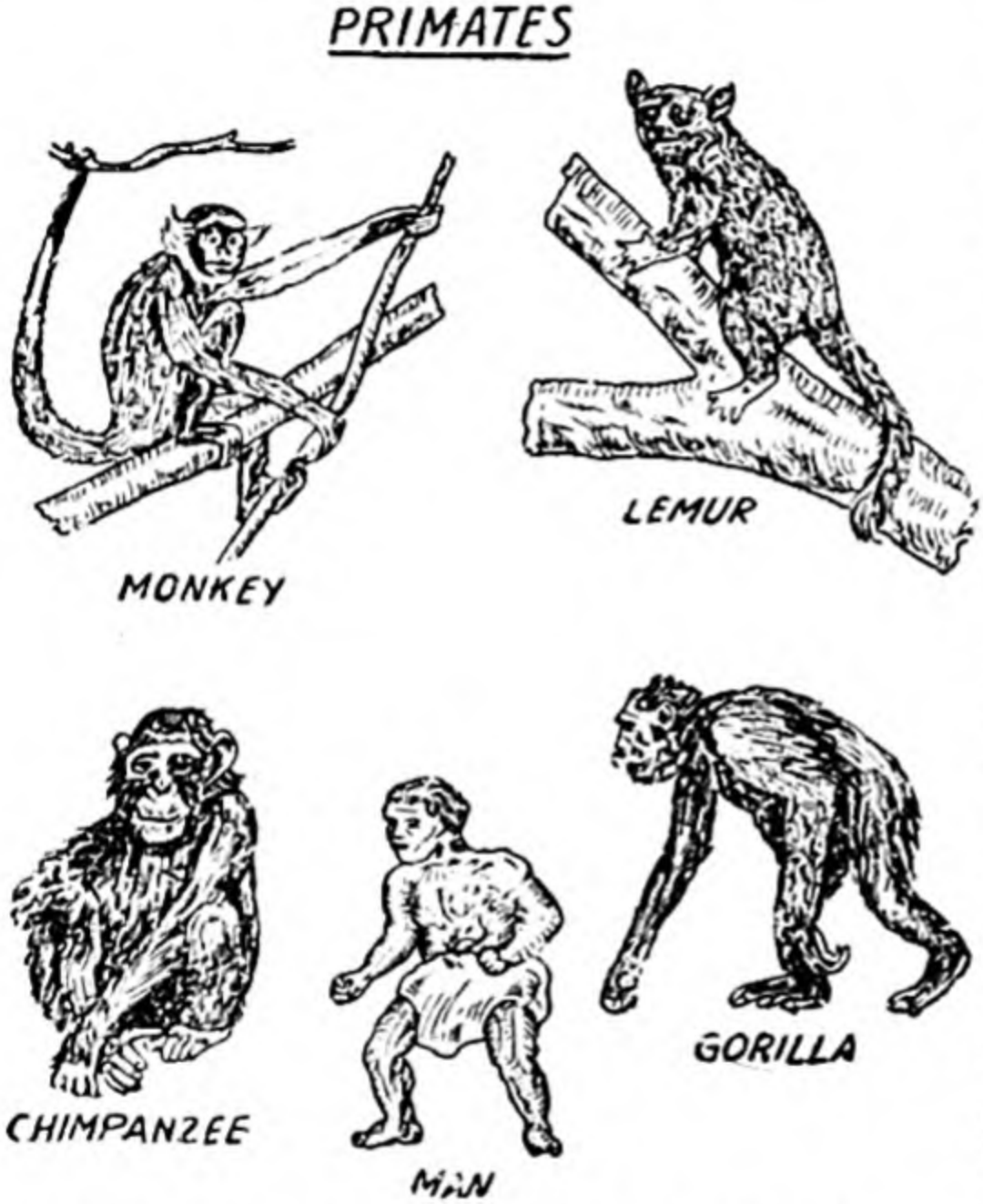

Fig. 202. Class Mammalia *(continued).*

The apes, namely, the gibbons, orang-utan, gorilla and chimpanzee have common ancestors with man. They have no tail and can support the

weight of the body on the hind-limbs, which are shorter than the fore-limbs. The gibbon walks upright like man and the others walk in a semi-erect manner on the soles of their feet with the backs of their hands on the ground. In the typical monkeys the tail is present and they walk on all fours. The gorilla is a ferocious creature and cannot be tamed, but the chimpanzee has a lively and gentle disposition and can be easily tamed. Most of the experiments on the behaviour of apes to determine the level of their intellect have been performed on the chimpanzee. The gibbons are found in south-eastern Asia, the orang in Borneo and Sumatra, and the gorilla and chimpanzee in West Africa. Man (*Homo sapiens*) has a world-wide distribution. The hairy covering is much reduced, particularly on the back. He walks erect on the soles of the feet, the hind-limbs being longer than the fore-limbs. The hand is a perfect grasping organ. The brain is about twice the size of that in the chimpanzee or gorilla. The mental faculty in man has developed to such an amazing degree that he may be inclined to consider himself superior to and distinct from all other animals, but the animal nature in him—the instinct of self-preservation—often asserts itself to the degradation of the human race. He has still to learn the art of living together and working together from such humble creatures as the bee and the ant.

CHAPTER XXVIII

VARIATION

It is a matter of common observation that no two human beings are exactly alike. They differ from each other in the size of body, colour of skin, facial make up, hair, voice etc. Even twins are somewhat different from each other and the mother can always distinguish between them. These differences in structure or function that occur among the individuals of a species are known as *variations*, which are found not only in man but in all species of animals and plants that inhabit the earth. Variation, thus, is a universal law of nature. It is an essential factor in the evolution of organic forms, for unless individuals vary there can be no new species and, thus, no evolution. There are two chief methods of classifying variations, according to the point of view from which we look at them, either into *somatogenic* and *blastogenic variation* or into *continuous* and *discontinuous variations*.

Somatogenic and Blastogenic Variations. As stated in an earlier chapter, the body of a multicellular organism is made up of somatic cells and germinal cells. The somatic cells perish with the death of the organism while the germinal cells are continuous from generation to generation. The hereditary characters are passed from the parents to the offspring through the germinal cells. Variations in an individual may be due to either environment or heredity. In the former case the variations are known as somatogenic while in the latter, blastogenic. The somatogenic variations are acquired by the individual during its life-time and not inherited from the parents. They are, therefore, also known as *acquired variations*. They affect somatic cells only and are, as a rule, not transmitted to the

offspring. The blastogenic variations are inherited and have their origin in the germinal cells of the parents. They are, therefore, also known as *germinal variations*.

It has been stated that somatogenic variations are due to environment, which includes a variety of factors, such as (1) the nature of the medium in which an organism lives, as also its temperature, pressure, intensity of light, etc., and the food which the organism takes, (2) use and disuse of organs, and (3) conscious effort in a particular direction.

The type of the medium or surroundings in which an animal lives has a profound influence on its form and functions as has been demonstrated by experiments. A flat fish has the lower surface white and the upper surface dark. It has been proved by Cunningham that it is due to the effect of light on the upper surface and to its absence on the lower surface. He placed a number of living specimens in a glass aquarium throwing the light from below and blocking all light from above. The result was that the lower surface of the fish became dark and the upper surface white. Stockard selected the fish *Fundulus* for his experiment. He added a small quantity of magnesium chloride to the sea-water in which the eggs of the fish were developing. He found that a large percentage of the young larva produced a single eye in the middle of the head instead of the normal two. The effect of food on growing children is often quite apparent. The child who gets nourishing food in proper quantities will be healthier and stouter than the one who is poorly fed, although both of them may belong to the same family and the constitution of their bodies may be similar. Other environmental factors which promote good health in children are fresh air, pure water and well-lighted dwellings. Such environmental factors similary affect other animals.

We are familiar with the effect of use and disuse of organs.

A labourer who makes a good use of his limbs has better developed muscles and greater strength than a shop-keeper who leads a sedentary life and does not use his limbs to any appreciable extent. A person who does not use his brain remains dull. A modern civilized man who is in the habit of taking soft food, requiring very little mastication, has much weaker teeth than the uncivilized man who takes hard and coarse food. A teacher or a singer has his vocal organs well-developed due to their constant use. Apart from use and disuse of organs modifications of certain parts of the body may be produced artificially by mechanical means. The small feet and slender waists of certain Chinese and European women respectively are examples of such modifications.

There are certain characters which we acquire through conscious effort, that is, by education and training. As little children we first learn to speak and then we learn to read and write. As we grow older we get training in variours arts and crafts and in many technical pursuits. We learn to swim, drive a car or play some game. All these come under the head of somatogenic variations, for they are acquired during the life-time of the individual and are not transmitted to the next generation. But when we look into them more carefully we find that they may not be altogether independent of heredity. In order to attain a certain standard of proficiency in any branch of learning or handicraft a minimum standard of basic intelligence is essential. This is provided by heredity.

The blastogenic variations have their origin in the germinal cells of the parents, and are inherited. From the point of view of evolution they are the only variations which matter, for the somatogenic variations are lost with the death of the individual as they are not inherited by the offspring. The process by which blastogenic variations are caused is intimately connected with the mechanism of heredity, and will be dealt with in the next chapter.

Continuous and Discontinuous Variations. Continuous variations are small variations which fluctuate on either side of a typical condition. Hence they are also known as *fluctuating variations* or *fluctuations*. They are called continuous variations for they pass into each other by small or even imperceptible gradations. They occur so frequently and universally as to form a characteristic feature of all plants and animals. In man continuous variations may relate to such characters as height and colour of body, and shape of various organs like eyes, nose, hands, etc. All these variations fluctuate both on the plus as well as the minus sides of the specific mean of each character.

Discontinuous variations are not slight but abrupt deviations from the typical condition and are not connected with the later by inter-gradations. They are also known as *mutations* or *sports*, and the organism in which a mutation occurs is called a *mutant*. A mutation appears suddenly and is widely different from the type. It does not fluctuate about the old mean but establishes a new mean of its own. Like fluctuations, mutations are inherited by the offspring. They are relatively rare but examples are found both among plants and animals. Among plants mutations may take such forms as differently coloured flowers, double flowers, dwarf variety, climbing variety or differently shaped leaves. Many of our garden plants have been produced in this way. The orange-coloured Baugainvillea, known as Louis Wathen, is a sport from the common red variety, Mrs. Butt. Many climbing varieties of roses have arisen in the same manner from similar dwarf or bush varieties. Among the animals the classical example of the Ancon or Otter Sheep may be quoted. It has a proportionately long body and short legs. It arose as a sport from the ordinary sheep in 1891 and became the founder of a new breed.

CHAPTER XXIX

HEREDITY

The transmission of characters from parent to offspring by the germ-cells is known as *heredity*. The science of heredity is called *genetics*. The offspring inherits from the parents, strange though it may seem, not only those characters in which it resembles them but also others in which it differs from them. The differing characters appear in the offspring as blastogenic variations.

Physical Basis of Heredity. All animals which come into being as a result of sexual reproduction, arise from a single cell, the fertilized ovum. It is not a matter of chance that the egg of a frog hatches into a tadpole and that of a hen into a chick. There is something in the eggs of these animals which causes them to develop into forms which are characteristic of their respective species. In other words the whole course of development from the egg to the adult is represented in some form in the egg and development is nothing more than the unfolding of characters which are already there. How this is accomplished is one of the most remarkable feats of nature when we know that many of the animal eggs are no larger than the point of a pin. Even in large sized eggs the living substance is only a minute speck of protoplasm the remaining part being yolk. As a fertilized egg is formed by the union of the male and female germ-cells (ovum and sperm), it is the protoplasm of the germ-cells which is the physical basis or carrier of heredity. This fact was put forward by Weismann in his theory of the *Continuity of the Germ-plasm*, according to which the body of an organism consists of two parts, the *germ-plasm* and *somatoplasm*. The former, which is the protoplasm

of the germ-cells, carries the hereditary characters and is continuous from generation to generation, while the latter, which constitutes the remaining part of the body of the organism, perishes at the death of the organism, and takes no part in heredity.

Research in Genetics has revealed that the hereditary characters are determined by 'factors' or *genes* which are arranged in a linear order in the chromosomes. The number of genes is exceptionally large. It has been estimated that there are as many as a million genes in a fertilized human egg. All heritable characters, however small and insignificant they may be, are controlled by the genes. There will, thus, be genes for such characters as the height of the body, colour of the eye, shape of the nose, texture of the hair, aptitude for gardening, taste for music and nervous temperament. The genes are, of necessity, extremely small for a tremendous number has to be accommodated in the minute nucleus. Like the atoms, they cannot be seen but their behaviour can be demonstrated, and, in many cases, their position in the cell can be located.

Mechanism of Heredity. There has never been any doubt regarding the existence of the effects of heredity but the mechanism of heredity, that is, the exact manner in which characters are inherited, has been a subject of intensive research ever since the middle of the last century. As a result of these investigations we have arrived at conclusions which furnish an adequate explanation of the main facts of heredity.

During mitosis or cell-division (p. 18) when the chromosomes split longitudinally into two identical sets, the genes also divide with them so that the two daughter cells have chromosomes and genes identical with those of the mother-cell. The chromosomes in the somatic cells occur in pairs. The two members of each pair, known as *homologous chromosomes*, are similar, but differ from every other pair. There are two genes

which induce alternative expressions of a particular character. They are situated in the same relative position in the two members of a pair of homologous chromosomes. Such genes are known as *allelomorphs*. During gametogenesis (p. 20) the maturing gametes undergo a reduction division in which the number of chromosomes in the matured gametes becomes half of the original number. Before the reduction division the two homologous chromosomes of each pair come together, the process being known as *synapsis*. After synapsis the chromosomes separate, one chromosome of each pair going into one daughter cell and the other into the other daughter cell but which chromosome of each pair will go into which daughter cell is altogether a matter of chance. In a cell with four pairs of chromosomes there are sixteen possible combinations of chromosomes at the reduction division. As each new combination involves redistribution of genes, the hereditary characters carried by the gametes would have the same possible number of combinations, that is sixteen. In man there are twenty-four pairs of chromosomes in the primordial germ-cells. During the maturation of gametes at the reduction division there would be 16,777,216 possible kinds of sperms and 16,777,216 possible kinds of eggs. The possible types of fertilized eggs from this vast variety of sperms and eggs would be 281,474,976,710,656. This explains why no two human beings are ever exactly alike. The whole secret of the mechanism of heredity lies in the behaviour of the chromosomes at the reduction division during the maturation of the gametes, and the way in which these gametes subsequently unite to form zygotes.

Mendel's Laws of Heredity. Gregor Johann Mendel (Fig. 203) was born in 1822 and died in 1884. He was the first person to successfully conduct experiments in Genetics and to formulate the basic laws of heredity which to this day hold good. Mendel, born of German parents, was a monk in

the monastery at Brunn, Austria. He carried out breeding experiments with the garden pea (*Pisum sativum*), and published the results of his labours in 1865 in the proceedings of the local Natural History Society, but their importance was not realized for nearly thirty-five years. In 1900, long after his death, Mendel's laws were independently rediscovered by three botanists, De Vries, Correns and Tschermak, who deserve all credit for naming them after Mendel and making known his work to the scientific world. Mendel formulated two important laws, namely, the *Law of Segregation*, and the *Law of Independent Assortment*.

Fig. 203. Gregor Johann Mendel.

The *Law of Segregation* may be explained by an experiment on guinea pigs. We will take a single character, the colour of the coat, produced by one pair of genes. As all genes behave in the same manner, the study of one example will give us an understanding of all genes.

Suppose we select a male guinea pig, of pure breed, with a black coat and mate it with a female guinea pig, of pure breed, with a white coat (Fig. 204). This is known as a *monohybrid cross* for we are concerned here only with one character, ignoring the others The offspring of the first generation (also known as F_1 generation) from this cross will

be all black like the male parent which had no white in its ancestry. Thus the black dominates over the white which remains suppressed and fails to express itself. The gene for the black coat-colour is said to be *dominant* and that for the white coat-colour *recessive*. If now the black males and females of the first generation are allowed to mate among themselves, the second or F_2 generation will have both black and white offspring in the ratio of three to one. This shows that the gene for the white colour was not lost in the first generation but was lying dormant and was able to produce white coats in some of the offspring in the second generation.

These results can be explained by reference to the genes. There are two genes for coat-colour in the cells of each guinea pig. The original black male had both of its genes for black while the original white female had both of its genes for white. They were, thus, pure or *homozygous* for their respective coat-colours. There is, however, only *one* gene for coat colour in each gamete. During the maturation of gametes at the reduction division the number of chromosomes is reduced to half which results in the separation or *segregation* of the two genes of each pair, leaving one gene in each gamete. So each sperm from the original black male has a gene for black and each egg from the original white female has a gene for white. When the sperms unite with the eggs, zygotes are formed which carry one gene for black and one for white. The black gene being dominant, all the offspring of the first generation have black coats, which are just as black as if the zygotes had two genes for black. But as each zygote carries a gene for white, though in a dormant condition, the guinea pigs are impure black or *heterozygous*. It should now be easy to follow the behaviour of the genes and their effect on coat-colour of the offspring in a cross of the first generation hybrids among themselves. Such a cross, in the second generation, gives a ratio of three black to one white. Of the black offspring one-

third are homozygous for black and two-thirds are heterozygous, while all the whites are homozygous for white.

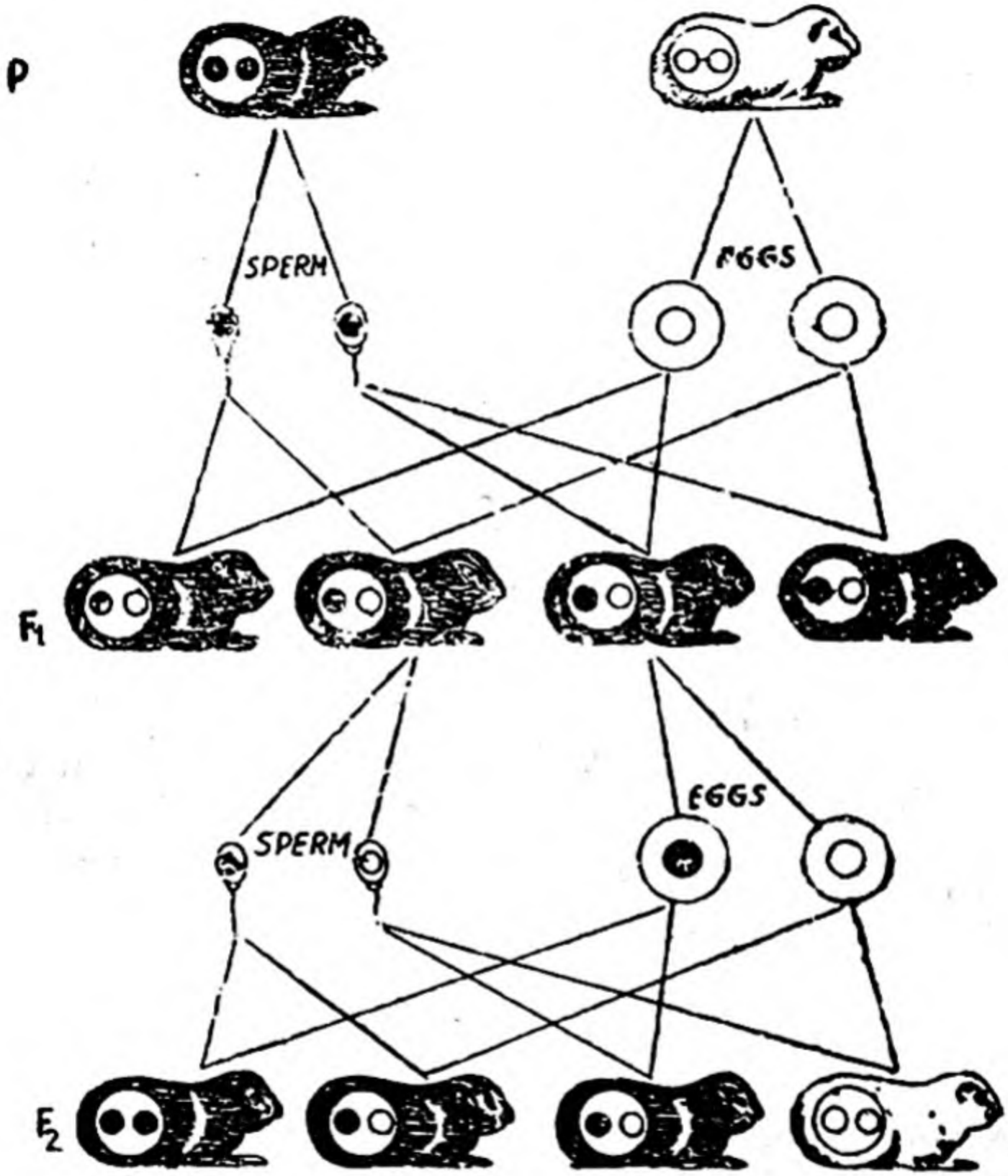

Fig. 204. A monohybrid cross to illustrate Mendel's Law of Segregation. (From Winchester). (For explanation see text).

Sometimes the hybrids do not resemble either parent with respect to a particular character but show an intermediate

condition, which is known as *incomplete dominance.* In such cases the dominant character does not completely prevent the

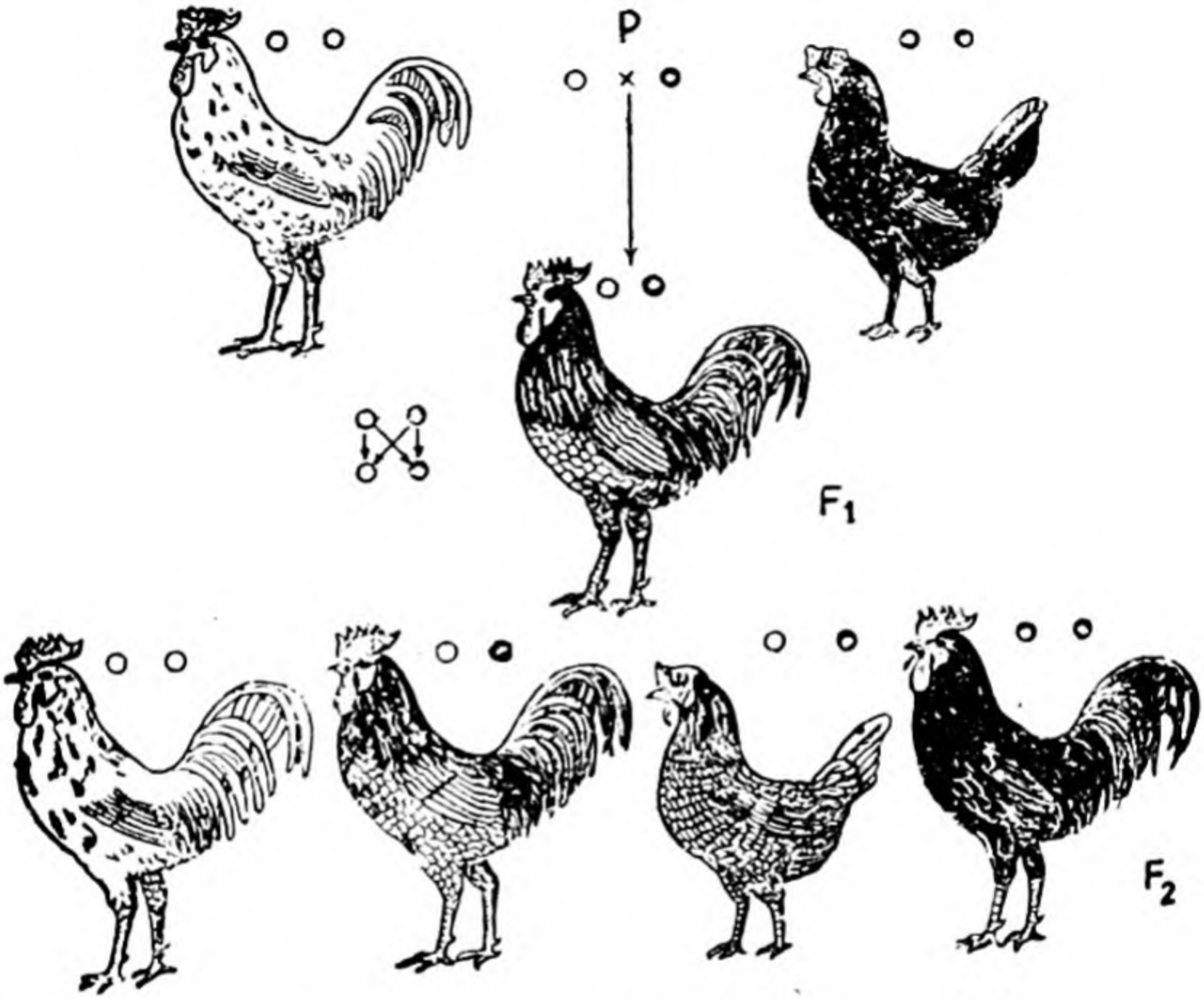

Fig. 205. Incomplete dominance in the Andalusian fowl. (From Woodruff). (For explanation see text.)

appearance of the recessive character. It is obvious that in a case of incomplete dominance the proportion of pure forms and hybrids can be determined without further crossing.

The well known Andalusian fowl (Fig. 205) illustrates the occurrence of incomplete dominance. It has three varieties, white, black and blue. The blue appearance is due to the black streaks on the white feathers. The white and the black fowls

are pure for their respective colours but the blue variety is a hybrid obtained by crossing a white fowl with a black one. If the blue hybrids are crossed with one another the offspring would be in the ratio of one white, two blue and one black, which is the usual Mendelian ratio for monohybrids.

Let us now consider the second law of Mendel, the *Law of Independent Assortment.* According to this law the different kinds of genes present in the cells of animals and plants are independent of one another in their hereditary behaviour and expression. This can be illustrated by taking two characters of the guinea pig, the colour of the coat and the length of the hair (Fig. 206). The gene for black colour is dominant over that for white colour and the gene for short hair is dominant over that for long hair. Suppose we cross a homozygous black short-haired guinea pig with a homozygous white long-haired guinea pig. Such a cross is known as *dihybrid*, as, two characters are involved in it. The offspring in the first generation will have one gene each for black and white colour, and one gene each for short and long hair. As the genes for black colour and short hair are dominant over the genes for white colour and long hair respectively, the coats will all have black colour and short hair. In the gametes produced by these individuals there will be four combinations of genes, namely, black short, black long, white short and white long. When two of these individuals are crossed they produce four types of guinea pigs in the second generation in the ratio of nine black short, three black long, three white short and one white long. Thus the Law of Independent Assortment becomes evident. The genes for black and short hair were together in the original cross but became separated from each other and some of them combined with other genes. In other words their assortment or grouping with other genes was independent of each other. This explains why the children of the same parents may show considerable degree of variation. The many genes determining their characters

arrange themselves in different combinations.

Application of Mendel's Laws. The breeding of animals

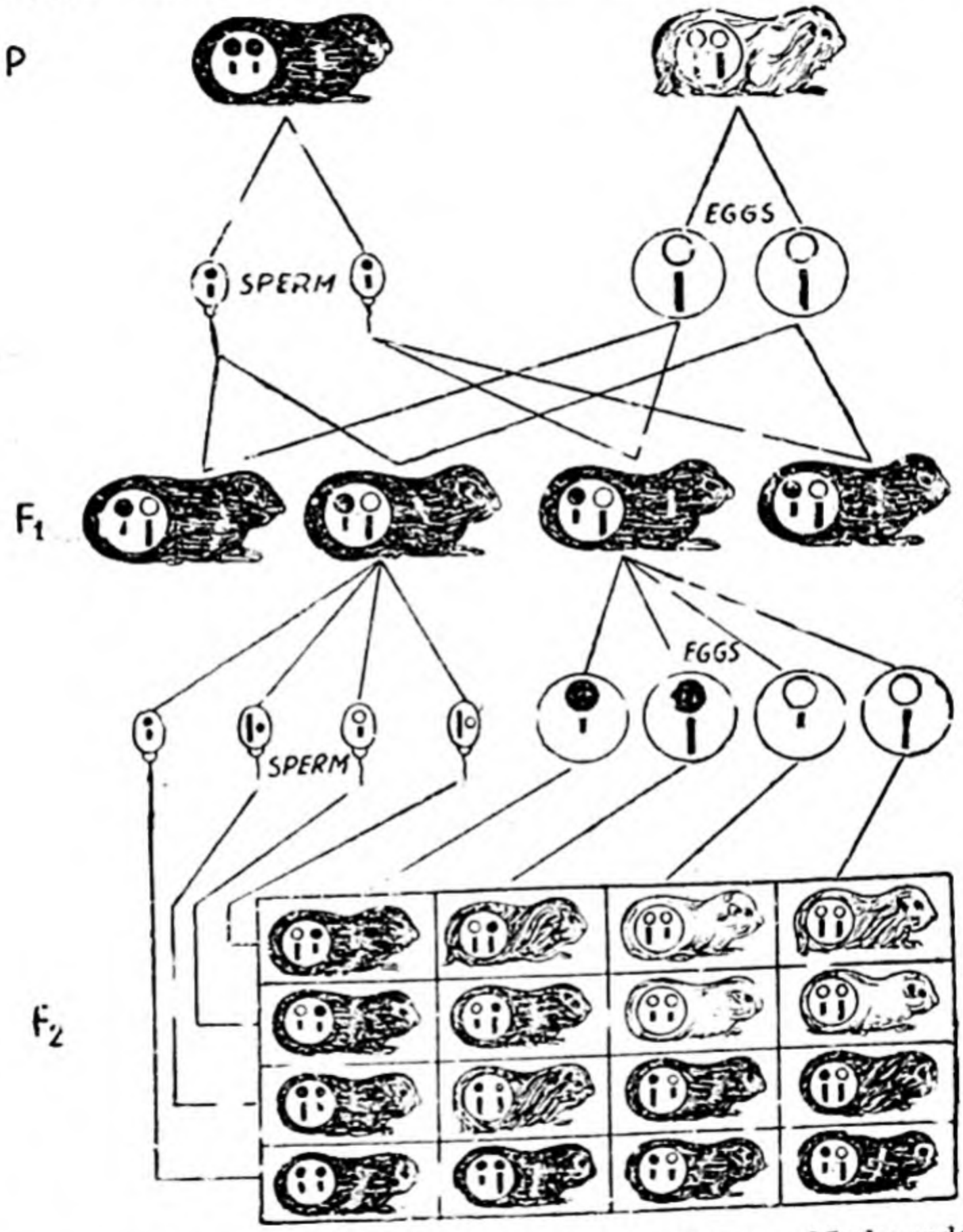

Fig. 206. A dihybrid cross to illustrate Mendel's Law of Independent Assortment (From Winchester). (For explanation see text).

and plants was practised even before Mendel gave us his epoch-

making laws of heredity but unlimited energy, time and material were wasted on the chance-experiments which the breeders used to perform. Very often quite unexpected and puzzling results were obtained and the breeder had no explanation for them. No doubt he sometimes succeeded in producing new varieties but that did not give him any scientific experience which he could utilize in other cases. After the discovery of Mendel's laws the breeder finds himself on a surer ground. Most of his perplexing problems are already solved. Not that with the knowledge of Mendel's laws he can achieve anything that he desires, but at least he knows his limitations and, unlike his predecessors, does not attempt to achieve impossible things. He, for instance, knows the difference between a pure and a hybrid form, although both of them may look exactly alike. In other words he knows that a hybird, unlike the pure form, can never breed true He also knows that as different characters are transmitted independently of one another, they can be separated and only the desirable ones selected, to improve the breed of an animal or a plant. Let us now take an example to show how practical problems may be solved by the application of Mendelian principles. As already stated the Andalusian fowl has three varieties, black, white and blue. The blue variety is the one which is always in demand and the other two are considered as 'wasters'. We know that the blue Andalusian is a hybrid and that the so-called wasters are the parent forms, for if we cross the two kinds of wasters we invariably get the blue form. If, however, the blues are crossed with one another, the offspring will be in the ratio of one black, two blues and one white. The old unscientific type of breeder, in this case, would go on destroying the wasters and carefully keeping the blues in order to maintain the "purity of the breed" But he does not know that there can never be a true breed of the blue Andalusian fowl, as it is a hybrid. In order to get more

blues he should mate the two kinds of wasters rather than mate the blues among themselves.

Galton's Laws. Francis Galton (1822—1911) was a cousin of Charles Darwin. He formulated two laws, known as the *Law of Ancestral Inheritance* and the *Law of Filial Regression*.

According to the *Law of Ancestral Inheritance* an organism derives one half of its inherited qualities from its parents (one-fourth from each parent), one-fourth from its grand-parents, one-eighth from its great-grand-parents, and so on. The total of the series equals one, or complete inheritance, as represented below :

$$\frac{1}{2}+\frac{1}{4}+\frac{1}{8}+\frac{1}{16}+\frac{1}{32}+\frac{1}{64}+\ldots\ldots\ldots\ldots=1.$$

The individual, thus, inherits half of its characteristics from the parents and the remaining half from all the other ancestors.

According to the *Law of Filial Regression*, if the parents deviate markedly from the average condition of the race in any particular character, the offspring will have a tendency to revert or *regress* towards the average condition. This is due to the fact that the hereditary influence of the remote ancestors tends to counteract that of the parents, which, after all, contribute only one half of the total inheritance. This explains why the exceptional men and women of the world, in the realm of science, religion, art, literature, poetry, music, sport or any other pursuit, get children who, as a rule, never rise to any great heights but grow up into mediocre men and women. In the words of Professor Karl Pearson, "It is the heavy weight of this mediocre ancestry which causes the son of an exceptional father to regress towards the general population mean ; it is the balance of this sturdy common-placeness which enables the son of a degenerate father to escape the whole burden of the parental ill".

CHAPTER XXX

ORGANIC EVOLUTION

The surface of the earth at the present moment is inhabited by myriads of animals and plants, exhibiting endless variety in form and structure. From the top of the snow-covered peaks of the high mountains down to the bottom of the sea, in all situations where life is possible, there is abundance of living organisms. This is particularly true of animal life. There is hardly any place, be it the dreary deserts, bleak mountains, frozen hill-lakes, sunny meadows, dense forests or dark caves, where some kind of animal life is not in evidence. And the last, though not the least, the vast oceans occupying three-fourths of the earth's surface are inhabited by an infinite variety of aquatic life in countless numbers. It is natural for a biologist to ask from where all these animals and plants have come. Two theories have been advanced to answer this question. They are known as the *Theory of Special Creation* and the *Doctrine of Organic Evolution.*

Theory of Special Creation. According to the theory of Special Creation all the species of plants and animals which exist on the surface of the earth today came into being as a result of a series of special acts of creation performed by the Creator. They are now as they were in the beginning without any change, and they are not to change in the future. Each kind of plant or animal was designed to suit the particular environment in which it was placed. This theory was taught by the church in the middle ages, and is based on the biblical account of the creation of life given in the Book of Genesis. It is not supported by any evidence and cannot explain many of the biological phenomena which are characteristic of living

things. It is, in fact, not a scientific but a religious theory and it is doubtful if it should find a place in a book of science. But its inclusion serves at least one purpose. It shows how intelligent men and women, sometimes, are swept away by religious dogma. The great pioneers of evolutionary biology, like Buffon Erasmus Darwin and Lamarck, and later Charles Darwin and Alfred Russel Wallace. showed great courage in opposing the church and convincing the people of the futility of this theory.

Doctrine of Organic Evolution. According to the doctrine of Organic Evolution the present species of animals and plants did not come into being all at once but descended from pre-existing species by gradual steps in the course of ages. The species. thus, are subject to change and may be modified into new species. Life began on the earth after it had solidified from a molten state and had sufficiently cooled down to be fit for habitation, but it must be admitted that we have no definite knowledge of how the first living thing came into existence. The first forms were simple but by a slow and continuous process of evolution they gave rise to more and more complex forms so that today we find a great variety of organisms which can be arranged in a more or less regular gradation from the simplest to the most complex forms. There are, no doubt, gaps in the series. It is because the present animals and plants do not represent the complete evolutionary history of life. Many forms, both large and small, have departed for good leaving behind, in many cases, fossils as a proof of their past existence. Man came last of all, he had no direct contact with them. By the study of fossils and the living forms he has built up "the tree of life" showing how different groups evolved from other groups (Fig. 171).

The doctrine of Organic Evolution is now almost universally accepted as the true explanation of the origin of diverse forms of animals and plants. If there is any difference of opinion among biologists it is in respect of the *manner* in which

evolution has taken place but none in regard to the *fact* of evolution itself.

Evidences of Organic Evolution. The student who has carefully read through the preceding pages must have observed that in all branches of Zoology the known facts can be reasonably explained on the basis of organic evolution. He must have noticed a fundamental 'unity in diversity' running throughout the animal series. The similarity in various physiological processes, such as respiration, nutrition, etc., the cellular structure of all organisms, the origin and fate of the three germinal layers, the comparative anatomy of vertebrates, particularly that of the skeletal, vascular and nervous systems, and the mechanism of heredity establish a fundamental relationship between all animals, which is a convincing proof of their common descent. The main evidences in support of the doctrine of Organic Evolution are of three types, namely, *anatomical, embryological* and *palaeontological.*

Anatomical Evidence.

(1) *Classification.* The classification of animals is chiefly based on anatomy From it we learn that there is a progressive series of animal life from *Amoeba* to man, which indicates that the higher forms have evolved from the lower forms. The same can be said of a particular system or organ which becomes more and more complex as we proceed from the lower to the higher groups. Take for example the heart in the vertebrates (Fig. 207). In the fishes the heart is two-chambered, with one auricle and one ventricle. In the amphibians it becomes three-chambered, the auricle being divided into two. In most of the reptiles the ventricle is incompletely divided, but in the crocodiles it is completely divided Thus the heart becomes four-chambered. This condition is continued in the birds and mammals. This gradual modification of the two-chambered heart of the fishes into the four-chambered heart of the birds

and mammals fits in with the concept of descent with change but cannot be explained by the theory of Special Creation.

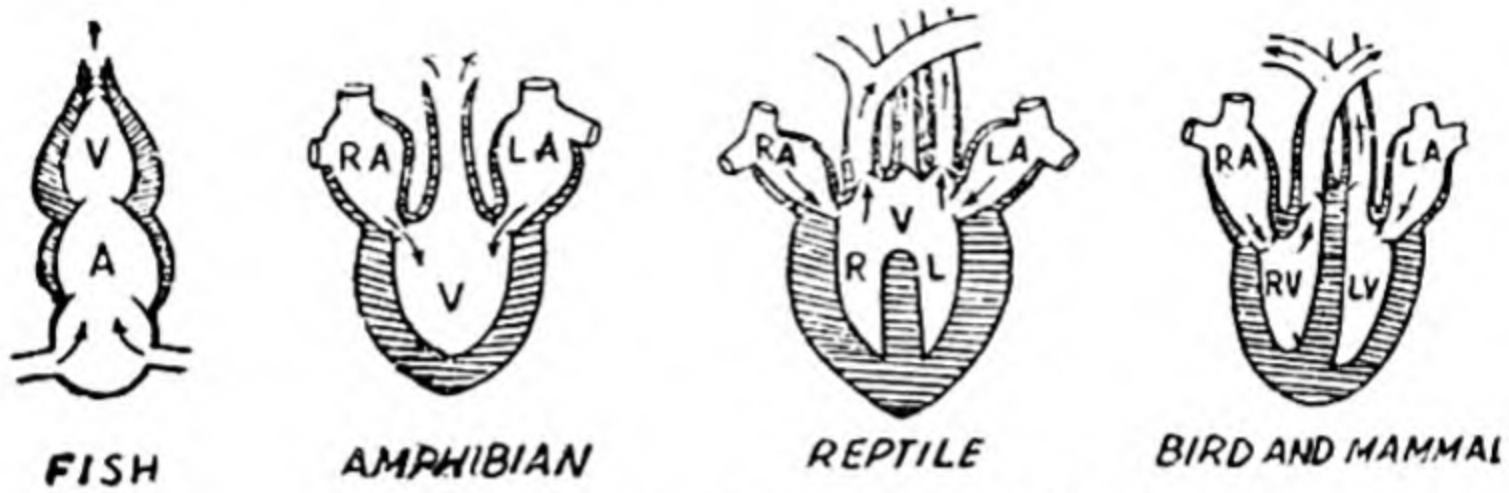

Fig. 207. Comparison of the hearts of different vertebrates. (From Storer).

(2) *Connecting Links.* If all animals which have ever lived on the surface of the earth were present to-day it would become a very difficult task to classify them into groups, for there would then be a complete series of forms merging into one another and the taxonomist would not know where to break the series to divide them into distinct groups. But to make his task easy, nature has broken the series at innumerable points. There are, however, certain forms, which come in the way of this distinction in animal groups, for they possess characters of two groups and cannot be easily placed in either of them. These are known as *connecting links*, as they connect, so to say, two groups. Examples of connecting links are provided by the lung-fishes and the egg-laying mammals.

The lung-fishes, which have been placed in the sub-class Dipnoi (Fig. 190) of the class Pisces, are intermediate between the typical fishes and the amphibians, as they possess, in addition to gills, either a single or a double lung. The egg-laying mammals constitute the sub-class Prototheria (Fig. 197) of the class Mammalia, including only two forms, the Duck-billed Platypus and the Spiny Ant-eater. These forms are intermediate between the reptiles and mammals. They resemble the reptiles,

among other things, in laying eggs and in having a T shaped episternum. At the same time they possess hair and suckle

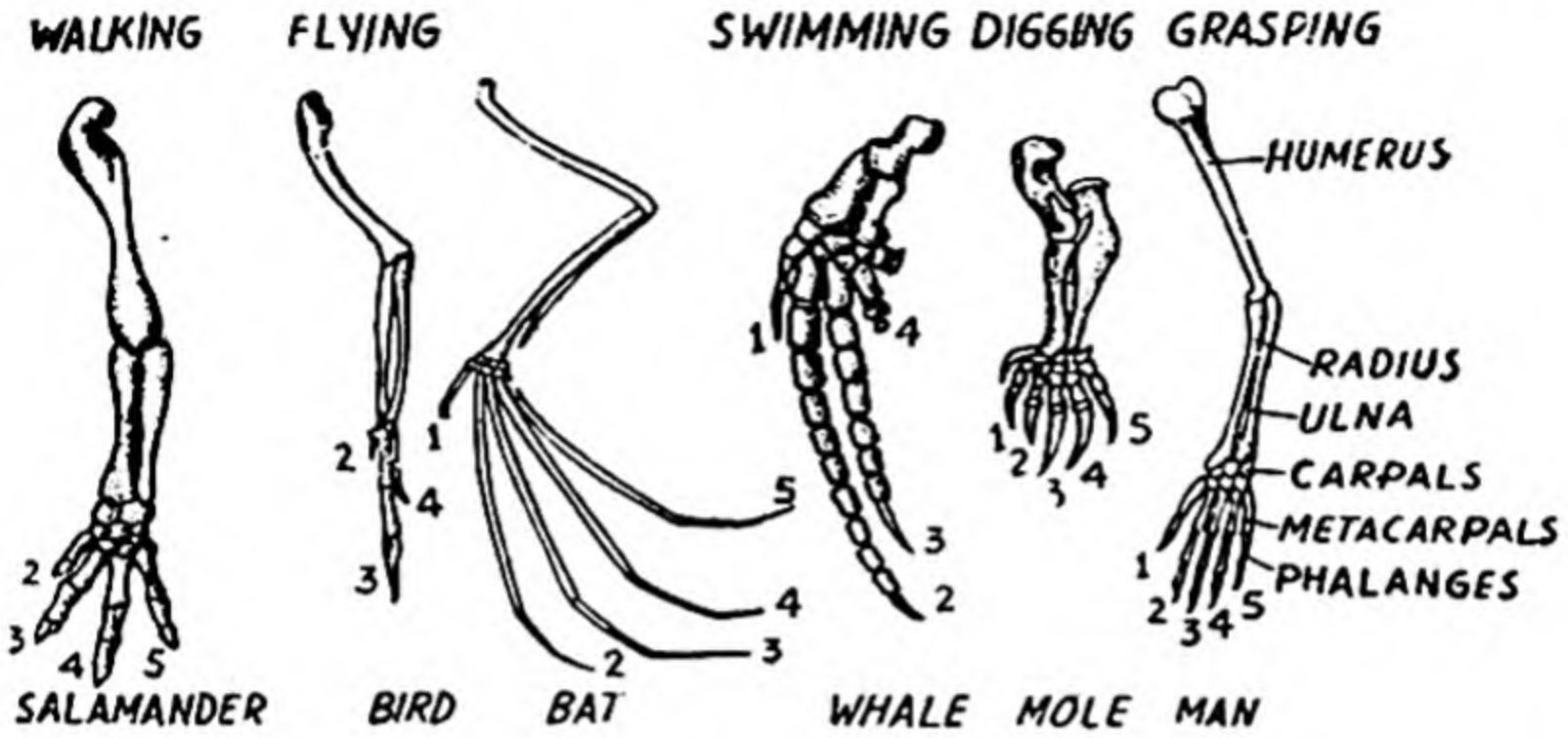

Fig. 208. Homology in bones of the left fore-limb in vertebrates. (From Storer).

their young which are mammalian characters. The existence of connecting links provides an indication of the path along which higher groups might have evolved from the lower groups. The presence of connecting links cannot be explained on the basis of the theory of Special Creation.

(3) *Homologous Structures.* We have already learnt that structures which are fundamentally similar, even though they may differ from one another in appearance and form, are known as homologous structures. In Fig. 208 the bones of the fore-limb in a salamander, bird, bat, whale, mole and man are shown. These limbs are used for walking in the salamander, flying in the bird and bat, swimming in the whale, digging in the mole and grasping in man. The limbs are modified in accordance with these functions, and have different forms. But when the bones forming the skeleton of the limb, in each case, are examined they are found to consist of the same parts, but in modified forms. Why should there be this fundamental

similarity between the different types of limbs, if they were made different from the very beginning, independently of one anotner, as the theory of Special Creation would have us believe ? The only satisfactory answer to this question is that all these limbs originally evolved from a common type, the pentadactyle limb, which became modified for special purposes during the course of evolution. Another example of homologous structures is afforded by the mouth-parts of insects. They consist of the same fundamental parts, namely, the labrum, two pairs of maxillae and a pair of mandibles, but are modified into various types according to the different modes of feeding, such as chewing in cockroach, piercing and sucking in the mosquito, siphoning in the butterfly and sponging in the house-fly.

(4) *Vestigial Organs.* In many animals, including man, there are structures which are reduced in size and are without any use to their possessors. Such structures are known as *vestigial organs.* Their presence cannot be explained by the theory of Special Creation according to which each organism was specially designed for the environment in which it was placed. So there is no room for useless organs. Their existence, however, can be explained on the basis of organic evolution, if we assume that they were functional and useful in the ancestral forms but, due to changes in environment and mode of life, they gradually became reduced to mere vestiges.

There is a large number of vestigial organs in man (Fig. 209). The muscles of the ear which move the pinna in certain other mammals, such as the horse, are present in man in a reduced condition. The vermiform appendix which is well-developed in herbivorous mammals, is a small blind diverticulum in man. A fold of the skin in the inner corner of the human eye represents the nictitating membrane of reptiles and birds. In the Kiwi (Fig. 195), a flightless bird of New Zealand, the feathers are reduced to almost hair-like structures and the wings are reduced beyond recognition, and are useless as organs

of flight. The bones and muscles of the wing, however, are present in vestigial form. In python, a kind of giant snake,

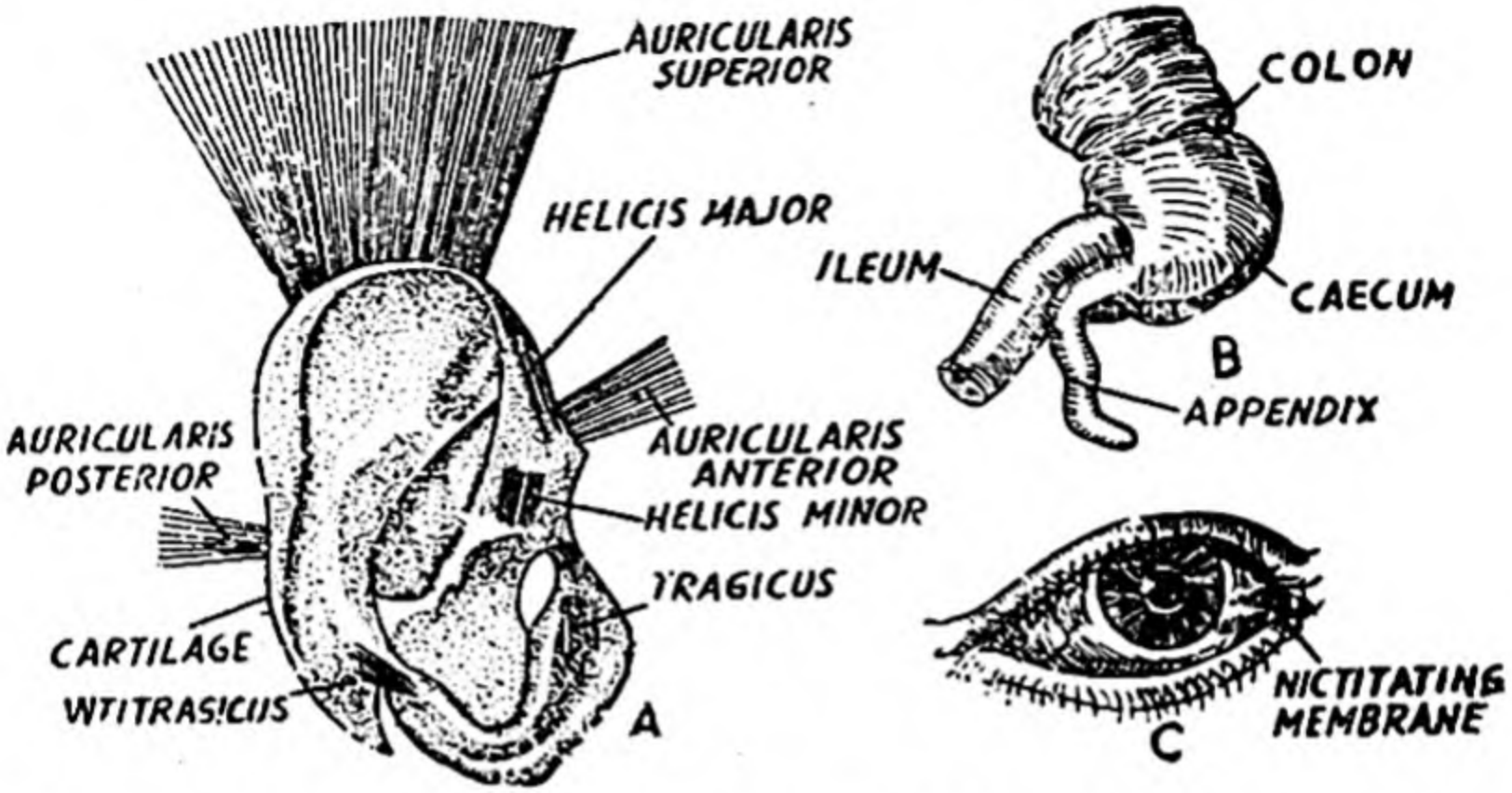

Fig. 209. Vestigial organs in man. A, muscles of the ear; B, vermiform appendix : C, nictitating membrane (From various authors).

vestiges of the pelvic girdle with tiny useless hind-limbs are present. The splint bones of the horse are remnants of functional toes of its ancestors. The blind *Proteus* of the Austrian caves has poorly developed eyes which are covered by the opaque skin, and are useless as organs of sight.

Embryological Evidence. Embryology furnishes a very strong evidence in support of the doctrine of Organic Evolution. The similarity in the early development of animals is so close that it would be logical to conclude that the various animals are related to one another and have descended from a common remote ancestor.

All Metazoa start life from a single cell, the fertilized ovum. This undergoes segmentation till there is a solid mass of cells, the *morula*. A cavity, the blastocoele, is formed inside the morula, which is thus converted into a single-layered

hollow ball of cells, the *blastula*. By an invagination of the wall of the blastula, or in some other way, it becomes a two-layered *gastrula*, with a new cavity, the archenteron inside it, which opens to the outside by the blastopore. The blastocoele in the meantime disappears. The two layers of the gastrula are the ectoderm and endoderm. The coelenterates, being diploblastic, develop no further than the gastrula stage. In the triploblastic animals a third layer, the mosoderm, appears betweeen the ectoderm and endoderm. The similarity in development does not stop here but is evident even in the fate of the three germinal layers which give rise to corresponding structures in the various animals into the details of which we need not enter here.

It has been observed that animals during development often pass through stages which resemble the adult forms of other animals belonging to lower groups. We have already seen that the frog, during its life-history, passes through a fish-like stage which is characterized by the presence of gills and a tail, and the absence of limbs. What is the significance of this phenomenon ? A very plausible explanation is provided by the *Recapitulation Theory* of Von Baer, according to which every organism during its individual life-history (*ontogeny*) recapitulates or repeats in an abbreviated form, the evolutionary history of its race (*phylogeny*), or briefly expressed "ontogeny repeats phylogeny." In other words the frog passes through a fish-like stage because it is descended from a fish-like ancestor.

It may be argued that the gills and the tail of the tadpole, due to its aquatic mode of life, are only adaptive characters and do not indicate its ancestry. But we find that even a bird or a mammal, which has no aquatic environment, possesses at an early stage of development visceral arches and gill-slits, and the blood-circulation is like that of a fish. It is remarkable that, due to a common ancestry, such divergent forms as a

fish, salamander, tortoise, chick, rabbit and man in their early embryonic stages so closely resemble one another that it is

Fig. 210. A group of vertebrate embryos in corresponding stages of development.

difficult to distinguish between them (Fig. 210). Further proof of the common descent of animals, from the study of Embryology, is furnished by the development of certain organs in the body. The heart, for example, is two-chambered in the fishes, three-chambered in the amphibians and most of the reptiles and four-chambered in the birds and mammals. It is significant that the heart of a bird or mammal, during its development, passes first through a two-chambered stage and then a three-chambered stage before it becomes four-chambered.

Palaeontological Evidence. The study of past organic life from fossils, which are the remains of plants and animals

on the earth, is known as *Palaeontology*. The evidence furnished by Palaeontology, in a way, is more reliable than other types of evidence, for it is direct, that is, it is based on the remains of *actual* animals which lived through the ages. If we had with us a complete fossil record of all the animals which inhabited the earth in the past, it would give us a definite proof of the truth of the doctrine of Organic Evolution, but unfortunately that is not the case.

The incompleteness of the geological record is due to various reasons. First of all it is only the hard parts of animals, like shells and bones, which can be preserved. Animals without hard parts, such as jelly-fishes and many kinds of worms, have left no fossils. Secondly, as fossil formation takes place at the bottom of the sea, many land animals could find no chance of reaching there. Thirdly fossils lying at great depths have been destroyed by pressure of the upper strata and by excessive heat. Fourthly many fossils lying deep at the beds of the oceans are out of man's reach and cannot be investigated. Some of these rocks, however, have been brought up by upheavals of the earth. And lastly even the accessible rocks have not all been thoroughly investigated.

There are two chief kinds of rocks, *igneous* and *stratified* or *sedimentary* The igneous rocks were formed when the molten earth cooled down and solidified. They are as old as the earth itself, and were all formed at one time. During the ages that followed the igneous rocks have been breaking down by the action of heat, cold, wind and rain. The broken down particles of these rocks have been steadily carried by the rivers to the sea where they have been settling down at the bottom in layers or *strata*, forming the stratified rocks. During the process of rock-formation at the beds of the great oceans countless marine animals, after death, have been sinking to the bottom and becoming embedded in the sediment. The remains of the

land animals also have been taken to the sea by the rivers and deposited at the bottom. Many of the stratified rocks, from time to time, have been brought above the surface of the ocean by upheavals, and have, thus, become accessible to man for investigation.

From the fore-going account of the formation of stratified rocks it is clear that the deepest layers are the oldest and the uppermost layers are the most recent, and in between these two the age of a particular layer is according to its depth. This natural arrangement, however, is sometimes disturbed by the action of volcanic eruptions and other causes. The stratified rocks, containing fossil remains and signifying the millions of years of earth's history, have been divided into three *eras*, namely, *Palaeozoic* or *Primary*, *Mesozoic* or *Secondary*, and *Cainozoic* or *Tertiary*. By some geologists the Cainozoic era is treated as two eras, *Cenozois* and *Psychozoic*. Each era is further divided into *periods* and *epochs*. The geological eras with their sub-divisions, together with the dominant forms of life in each era and its duration in millions of years, are shown in Figs. 211 and 212, which represent the evolutionary history of animal life, as far as is known from the fossils.

A study of these figures will show that the main trend of evolution has been from the simple to the more complex animals, which have taken millions of years to attain their present forms, and that many of the animals which were dominant during one period or another have become extinct. We, thus, see that the early Palaeozoic period was the age of marine invertebrates, followed by the age of fishes in the middle Palaeozoic, and amphibians were dominant in the late Palaezoic. Then we have the famous age of reptiles covering the whole of the Mesozoic period, when many queer monsters of the animal world, like the dinosaurs and pterodactyls, populated the earth. Toothed birds were also present. The age of mammals began with the Cainozoic era. More birds appeared but they had no

teeth. Primitive mammals were replaced by higher types, headed by the monkeys and apes. Finally man came on the

ERAS	PERIODS	EPOCHS	DOMINANT FORMS OF LIFE		AGE	Age in Millions of Years: Duration	Age in Millions of Years: From Present
PSYCHO ZOIC		Recent	Rise of Civilized Man (Mental Dominance) Age of Modern Insects, Birds & Mammals		AGE of MAN	·03	03
CENO ZOIC	QUARTERNARY	Pleistocene	Dawn of Civilization and Rise of Primitive Man Extinction of Great Mammals		AGE of MAMMALS	1	1
	TERTIARY	Pliocene	Appearance of Primitive Man Decline of Great Mammals			6	7
		Miocene	Maximum Mammalian Life Anthropoid Apes			12	19
		Oligocene	Rise of Higher Mammals Extinction of Archaic Mammals Rise of Anthropoids			16	35
		Eocene	Decline of Archaic Mammals & Rise of Placental Mammals			20	55
MESO ZOIC	LATE MESOZOIC	Cretaceous	Extinction of Dinosaurs & Pterodactyls Specialization of Birds & Reptiles Toothed Birds & Ammonites		AGE of REPTILES	65	120
	EARLY MESOZOIC	Jurassic	Rise of Toothed Birds & Giant Reptiles- Spread of Pterodactyls, Ganoid Fishes & Ammonites			35	155
		Triassic	Rise of Dinosaurs Origin of Bony Fish			25	190

Fig. 211. Table of geological eras. (After Macdougall and Hegner)

scene and took control of the whole world, and the age of man was ushered in.

ERAS	PERIODS	EPOCHS	DOMINANT FORMS OF LIFE		AGE	Age in Millions of Years: Duration	From Present
PALEOZOIC	LATE PALEOZOIC	Permian	Rise of Land Vertebrata, Rise of Ammonites & Modern Insects		AGE of AMPHIBIA	25	215
		Carboniferous: Pennsylvanian	Spread of Primitive Insects & Amphibia			85	300
		Carboniferous: Mississippian	Spread of Ancient Sharks, Culmination of Crinoid-Earliest Reptiles, Extinction of Trilobites, Decline of Nautiloids				
	MIDDLE PALEOZOIC	Devonian	Rise of Amphibic & Fish, First Crabs & Land Shells, First Spiders & May-flies		AGE of FISHES	50	350
		Silurian	First Air-breathing Animals (Scorpion & Insects) Dominance of Cephalopods, Rise of Jawfish Abundance of Coral			40	390
	EARLY PALEOZOIC	Ordovician	Rise of Fishes & Cephalopods, Rise of Corals, Culmination of Trilobites		AGE of INVERTEBRATES	90	480
		Cambrian	Rise of Shell bearing Molluscs Dominance of Trilobites			70	550
PROTEROZOIC			No Fossils, Age of Simpler Marine Invertebrates		Shell-less Invertebrates	730	1,280
ARCHEOZOIC			No Fossils, Evolution of Unicellular Life		Dawn of Life		

Fig. 212. Table of geological eras *(contd.)* (After Macdougall and Hegner)

Although fossil remains of different animals, unearthed by palaeontologists, are generally fragmentary, we are lucky in

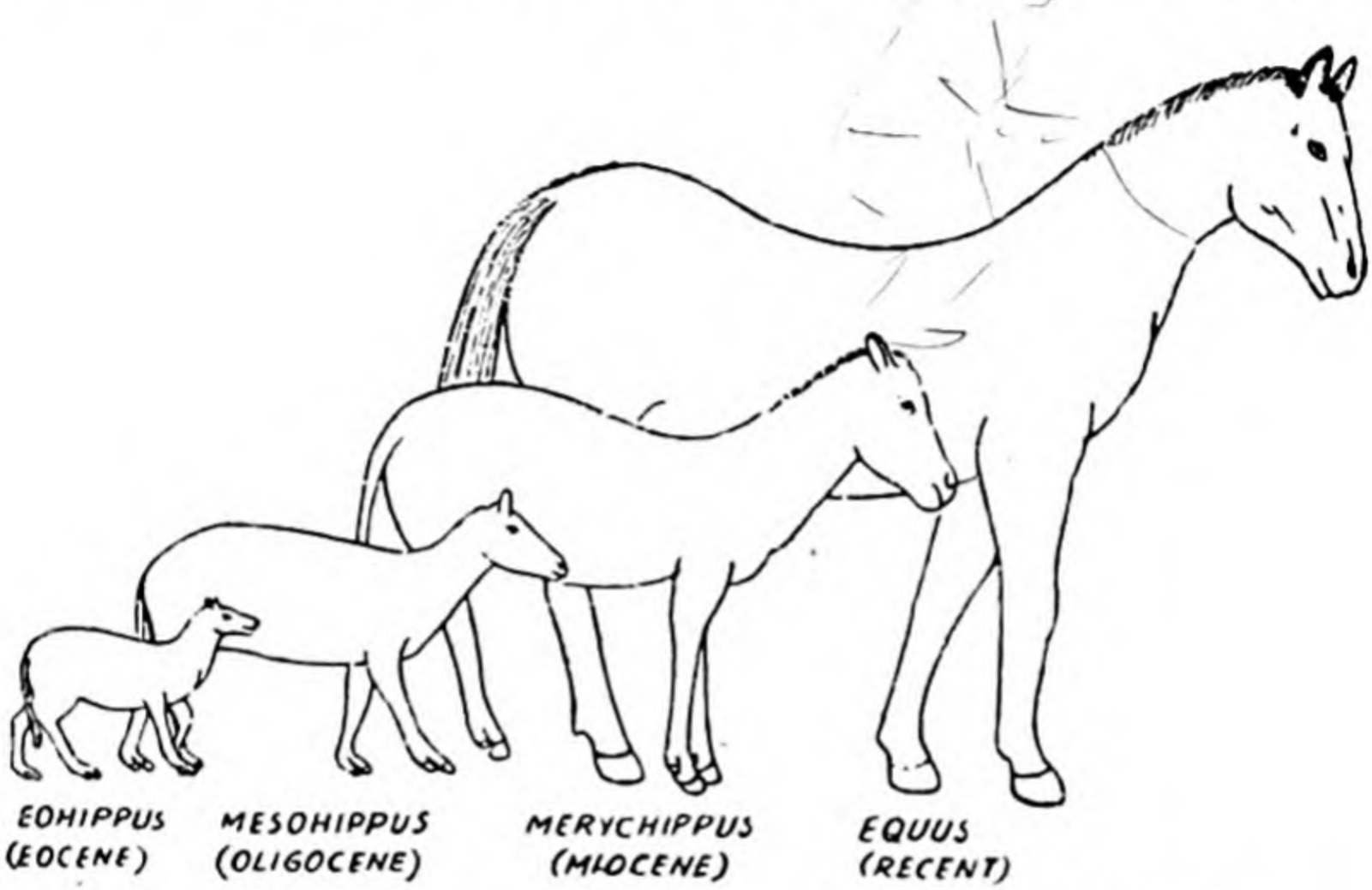

Fig. 213. The evolution of the horse. (From Wolcott, after Mavor)

having in our possession a few complete series of fossils illustrating the evolution of forms, like the horse, elephant and camel. The series of fossils representing the ancestry of the horse (Figs. 213 and 214) have been discovered from the Tertiary rocks of Europe and North America. The first horse-like animal, known as *Eohippus*, lived during the Eocene epoch. It was about twelve inches in height. Its fore-foot had four complete toes and a vestige of the fifth, while the hind-foot had three complete toes and a vestige of the fourth. These vestiges are known as *splints*. This small creature, no larger than a cat, through a number of other stages covering a period of forty million years, gradually lost some of its toes and grew up in size to become the modern horse (*Equus*), which has a single enlarged toe and two splints, in each foot.

An interesting form, which indicates the evolution of the present-day birds from reptilian ancestors, is known as *Archaeopteryx* (Fig. 215), the first bird to appear on the earth. Only two fossil remains of this primitive bird were found in the upper

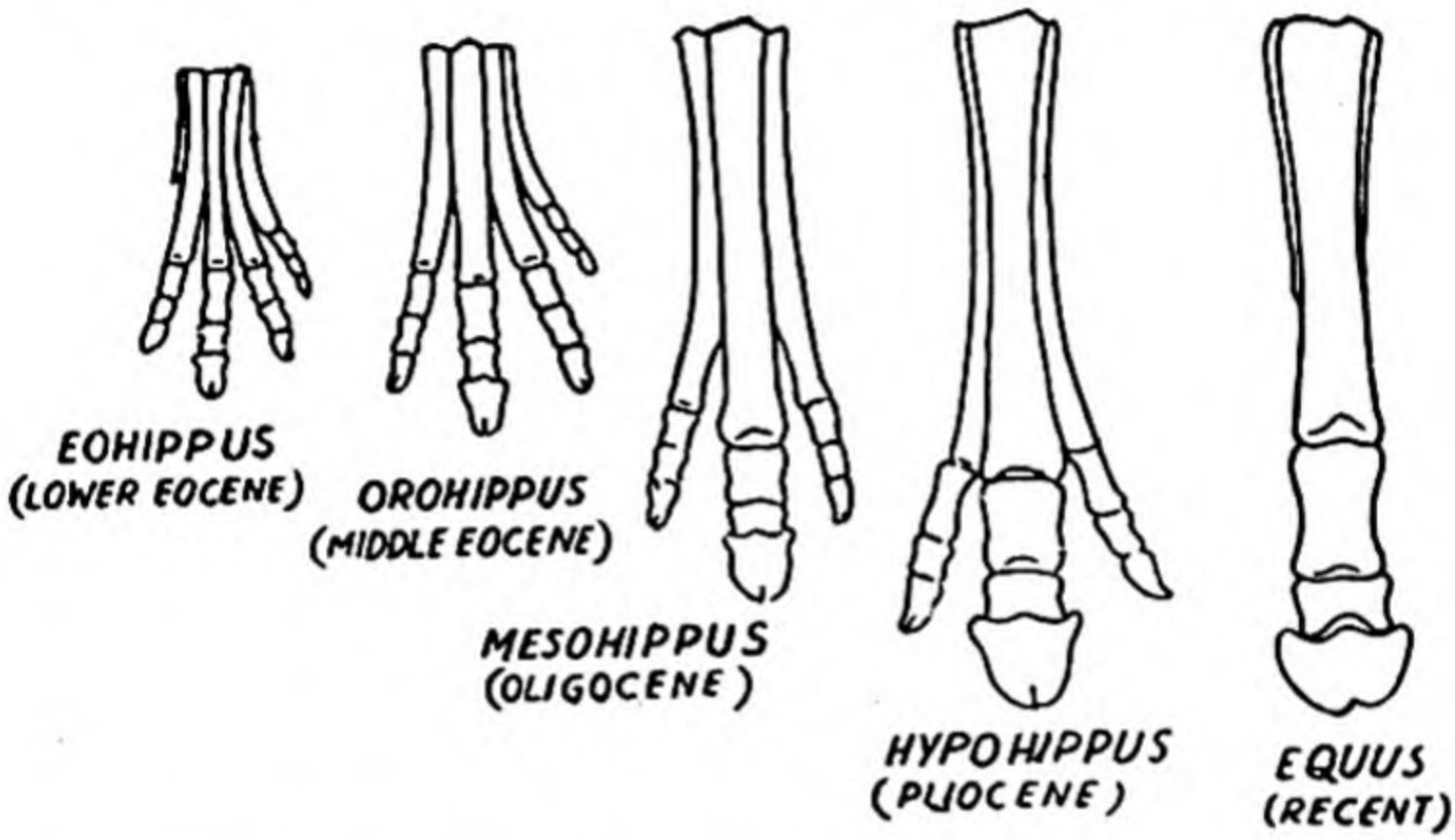

Fig. 214. The bones of the fore-foot of the modern horse compared with those of its ancestors. (From Swinnerton)

Jurassic and they are preserved in the Berlin Museum and the British Museum, London. *Archaeopteryx* has been placed among the birds as it had feathers, otherwise it had many reptilian characters. These include the toothed jaws, free fingers bearing claws, an elongated tail and a feeble keel-less sternum.

The facts of Palaeontology, no less than those of Anatomy and Embryology, furnish a convincing evidence of evolution. The occurrence of graded forms of life from the simplest to the most complex, as revealed by the study of Palaeontology and the discovery of complete series of fossils representing the evolutionary history of individual forms, like the horse, elephant and camel, lead us to the conclusion that the present forms of

animals are the descendants of other forms which existed before them.

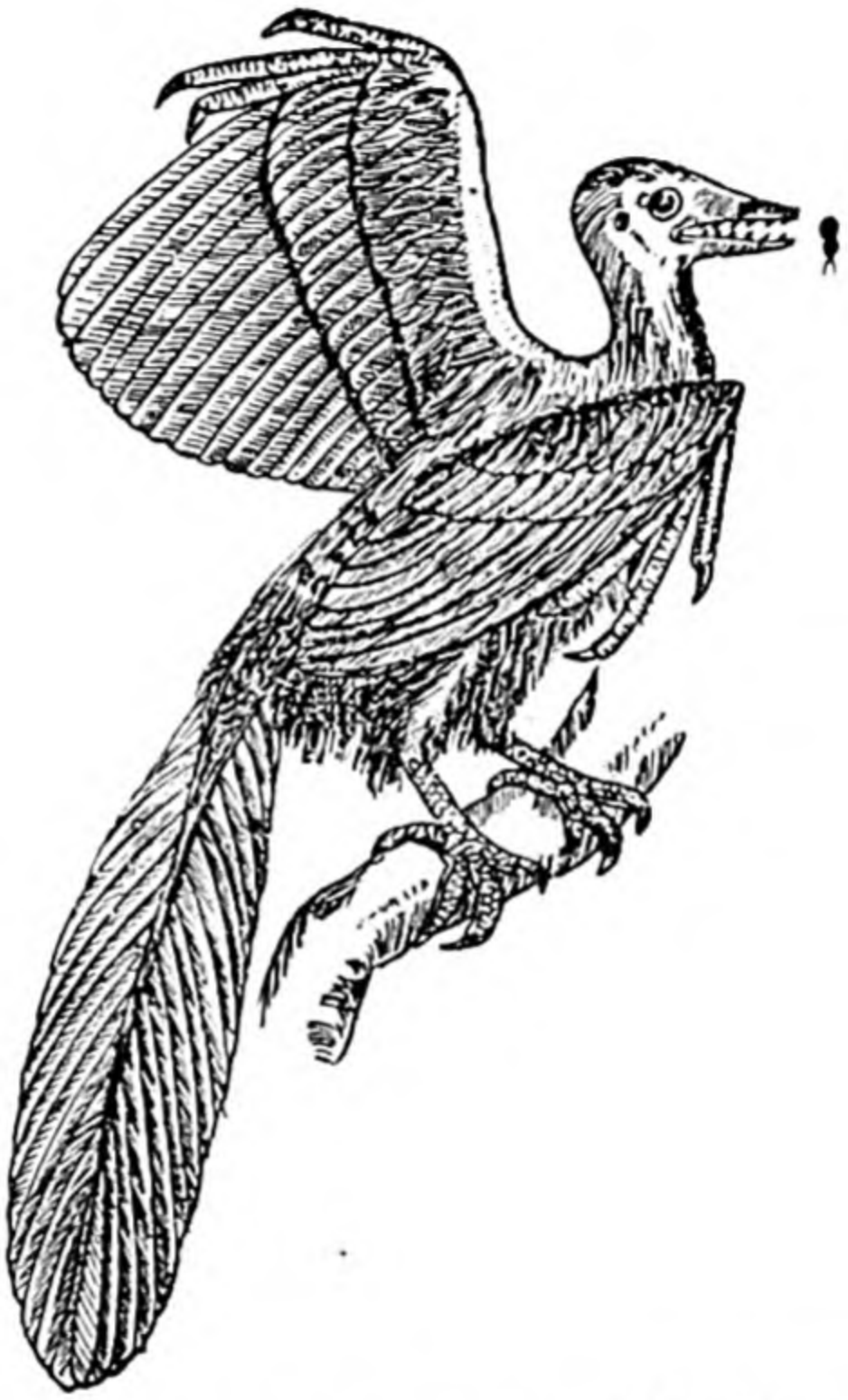

Fig. 215. Restoration of *Archaeopteryx*. (After Romanes).

Theories of Evolution. The doctrine of Organic Evolution is now accepted by all men of science and thinking laymen, but opinions differ as to the mode of evolution, that is, how one species is modified into another. There are three main theories of evolution, namely. (1) the Lamarckian theory, (2) Darwin's

theory of Natural Selection, and (3) the Mutation theory of De Vries.

Lamarckian Theory. Jean Baptiste Lamarck (Fig. 216) was a Frenchman who lived from 1744 to 1829. He was the first person to formulate a theory of evolution, now known as *Lamarckism*, which has retained a place in the scientific world up to the present time. His private life was full of hardships due to poverty, lack of sympathy and encouragement, and later due to complete blindness. His theory was explained in his *Philosophie Zoologique*, published in 1809.

Fig. 216. Jean Baptiste Lamarck.

Lamarck's theory briefed from his own words, is as follows: "The environment affects the shape and organization of animals; frequent continuous use develops and enlarges any organ, while by permanent disuse it weakens until it finally disappears; all acquisitions and losses wrought through influence of environment and hence through use and disuse are preserved by reproduction." This theory is made up of two parts, (1) the environment and the use and disuse of organs cause variations in animals, and (2) the variations so caused are inherited by the offspring. As

these variations are acquired during the life-time of the individual, the Lamarckian theory believes in the inheritance of acquired characters.

Lamarck's theory may be illustrated by some of the examples given in his writings. The ancestors of the present-day water-birds were terrestrial. Some of them, finding no food on land, went into water in search of it. They spread out their toes in order to move about in the water. This caused the bases of the toes to become stretched and more blood to flow to them. As a result, the skin extended between the toes to form webs, as are found in ducks, swans and other water-birds. The short-necked ancestor of the giraffe (Fig. 200) came to live in a barren place where the foliage of occasional trees was the only food available to it. The animal, therefore, made conscious and continual efforts to reach the leaves, stretching up its neck and the fore-limbs. As a result they became slightly longer. This increase in length was passed on to the next generation, in which the length was further increased through the same process. In this manner, after a number of generations the long-necked giraffe was produced. The lizard like ancestors of the snakes, with well-developed limbs, cultivated the habit of crawling through crevices and narrow spaces to protect themselves from the attack of mammals. In this process the body was elongated repeatedly and the legs were not used. Gradually the body became snake-like and, due to disuse, the legs were lost.

There is no dispute regarding the first part of the Lamarckian theory which relates to the effect on the individual of environment, and the use and disuse of organs, but the inheritance of that effect has become a very controversial subject. In other words the inheritance of acquired characters is the main issue on which the truth or falsity of the theory

depends. Let us, therefore, examine the arguments for and against the inheritance of acquired characters.

August Weismann (1834—1914), a German biologist, opposed the assumption of the inheritance of acquired characters in the Lamarckian theory. According to Weismann's theory of the *Continuity of the Germ-plasm* inheritance is the sole concern of the germ-cells and the somatic or body cells have nothing to do with it. As the environment and the use and disuse of organs affect only the somatic cells and not the germ-cells, the variations produced by them are not inherited. The basic principle of Weismann's theory is that any change in the somatic cells does not affect the germ-cells.

In most cases Weismann's assertion seems to be correct. The well-developed muscles of a wrestler are not inherited by his son, for, unless the latter becomes a wrestler, he would have muscles of an ordinary man. Most of the Indian women get their ears bored, and they have done it now for a few centuries, but their children are never born with bored ears. Similarly it has been shown by experiment that cutting off the tails of mice, even for many generations, does not affect the tails of their descendants. These examples clearly show that acquired characters are not inherited. But it has been observed that, sometimes, the somatic cells give rise to the germ-cells which is contrary to the principle of Weismann's theory. It is a common practice to propagate plants from cuttings taken from a twig, which is somatic in nature. But the new plants produced by this method bear flowers containing germ-cells. Similarly a part of the body of an earthworm without the germ-cells will regenerate into a complete worm containing the germ-cells.

During the present century there has been a revival of Lamarckism, known as *Neo-Lamarckism*. Experiments have been performed to show that environment can influence inheritance. The well-known experiments of Tower with the Potato Beetle demonstrate the direct effect of environment on

the germ-cells, without producing any change in the somatic cells. Tower exposed the potato beetles to varying degrees of moisture and temperature, when the reproductive organs were developing in them. The beetles so treated remained unchanged but their offspring showed marked variations in colour and pattern, which were inherited for a number of generations.

In view of the conflicting results obtained from experiments relating to the inheritance of acquired characters, it is extremely difficult to say with any certainty how far such characters are inherited. But taking everything into account it appears that, as a rule, the acquired variations are not inherited, although sometimes, for reasons still to be discovered, they may be inherited. If this view is correct then the Lamarckian theory does not furnish a satisfactory explanation of how organic evolution has taken place.

Darwin's Theory of Natural Selection. Charles Darwin (Fig. 217) was an Englishman. He was born in 1809 and died in 1882. He occupies the highest place among those who have been engaged in solving the riddle of evolution, for he has given to the world a most plausible explanation of how species have originated. His theory was not a result of momentary or a sudden flash of insight but the product of careful and sustained study of innumerable facts, extending over a period of twenty-two years. Darwin accompanied the surveying expedition on the ship *Beagle*, and during the voyage, extending over five years (1831-1836), made extensive observations on animal and plant life and brought back a rich and valuable collection of specimens. During this expedition he was chiefly impressed with infinite variety and wonderful adaptations to environment which organisms exhibited, and these two factors formed the foundation of his famous theory, known as *Natural Selection*.

In 1838 Darwin happened to read *Essay on Population* by Malthus in which the author had shown how population increased

in a geometrical ratio but food and space remained constant. There were thus forces at work, such as war, disease, famine, etc., which kept down the rising numbers. This led Darwin to formulate his theory of Natural Selection, which may be stated in the words of Darwin himself: "As many more individuals of each species are born then can possibly survive, and as, consequently, there is frequently recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving and thus be naturally selected. From the strong principle of inheritance any selected variety will tend to propagate its new and modified form."

Fig. 217. Charles Darwin.

It is a remarkable coincidence that both Darwin and Alfred Russel Wallace independently and simultaneously arrived at the idea of natural selection, by reading the same book, that is, Malthus's *Essay on Population*. In 1858 they wrote a joint paper which was read before the Linnaean Society of London. In 1859 Darwin published his epoch-making book, *The Origin*

of Species, which ranks among the greatest books of all times. The theory of Natural Selection is based on the following factors : (1) Universal Occurrence of Variations, (2) Excessive Rate of Multiplication, (3) Struggle for Existence, (4) Survival of the Fittest, and (5) Inheritance of Useful Variations.

(1) *Universal Occurrence of Variations.* We already know that variation is a universal law of nature and that no two individuals of a species are ever exactly alike. Darwin took the occurrence of small variations as an established fact and did not attempt to explain their origin. He believed that individuals possessing useful variations would have a better chance of survival than those without them. Variations, thus, form the raw material for natural selection to function.

(2) *Excessive Rate of Multiplication.* The most impressive thing about living organisms is their power of reproduction. The elephant is a very slow breeder, but Darwin calculated that a single pair, beginning to breed at the age of thirty and continuing to do so till the age of ninety, would normally produce six young, and would have in 750 years nineteen millions of descendants. An oyster may produce sixty million eggs in a season. If all the descendants of a single oyster survived and multiplied at this rate for five generations they would form a mass eight times the size of the earth. *Paramecium* divides three times in forty-eight hours. If its descendants could live for five years they would produce a volume of protoplasm approximately equal to ten thousand times the volume of the earth. It has been calculated that after 9000 generations "the mass would exceed the confines of the known universe and the rate of growth would be extending its circumference into space with the velocity of light".

(3) *Struggle for Existence.* The excessive rate of multiplication is, more or less, a common feature of all organisms. But as the space and food-supply are limited there is a keen struggle for existence between them. This struggle is particularly keen

among individuals of the same species (*intraspecific*), for their needs are precisely similar, but may also take place among individuals belonging to different species (*interspecific*). A third type of struggle is against the forces of nature (*environmental*), such as extreme heat or cold, excess of moisture or draught, lightening, earthquake and volcanic eruption. In this struggle for existence man is as much involved as other animals. He is constantly struggling against his fellow beings, other organisms and against forces of nature. The minute microbes cause numerous human diseases resulting in countless deaths. Floods, draught, scarcity of food. cyclones, and earthquakes claim a heavy toll of human life. Wars have become a common feature of international relationship. All these factors tend to check undue growth of human population.

(4) *Survival of the Fittest.* We have noted above that all organisms show variations and all are engaged in a struggle for existence. It is obvious that certain variations, however slight, are more useful in the struggle than others, and the possessor of such variations will have a better chance of survival than its neighbours. This process is known as the *survival of the fittest* or *natural selection*. In other words nature selects the fittest or those individuals which are best adapted to the conditions of life, and eliminates those which are not so adapted. This also explains why every organism in nature exhibits perfect adaptation to its particular environment and mode of life. Because if it did not have such adaptation it could not have been selected by nature but would have perished.

(5) *Inheritance of Useful Variations.* The useful variations, after being selected in the struggle for existence, are transmitted to the offspring, and become more and more pronounced in each succeeding generation till, after many generations, become modified to such an extent as to give rise to a new species.

Artificial Selection. By selective breeding man has produced many races or breeds of domesticated animals. He selects those individuals which possess, according to his own need or fancy, desirable variations and mates them with other individuals having similar variations. He discards the remaining individuals which do not show the required variations. This process when repeated for a few generations, gives rise to new varieties which breed true. In this manner man has produced numerous distinct races of domesticated animals and garden plants, from their wild ancestors. This process is known as *artificial selection*.

The wild race of the Indian Jungle Fowl has a small and slender body, and the hen lays only 12 to 24 eggs per year. Continued selective breeding has produced from it several domestic races differing from one another in size, coloration and egg-production. The Cochins, Pymouth Rocks and Rhode Island Reds are up to sixteen inches in height and six to eight pounds in weight, and the White Leghorn hen lays, on an average, 120 eggs per year. Over a hundred breeds of dogs are now known, including the Spaniel, Bulldog, Greyhound, Alsatian, etc. (Fig. 218). An even larger number of races of pigeons have been produced such as Tumblers, Pouters, Fantails, Carriers etc. They have all descended from the wild form, known as the Blue Rock-pigeon. Although many of the breeds of domesticated animals have been in existence for long periods none of them is stable. If they are bred indiscriminately they soon revert to the ancestral type.

Protective Resemblance and Mimicry. There are many instances of animals resembling a part of their inanimate surroundings. This makes them inconspicuous. It is a natural device to protect them from their enemies, and to conceal them from their victims, so that they should prey upon the latter without being noticed. A resemblance of this kind is known as *protective resemblance*. The animals of the arctic region, like the

polar bear, are snow-white, while those living in the deserts are sandy in colour. Similarly some forms, like the tiger and the

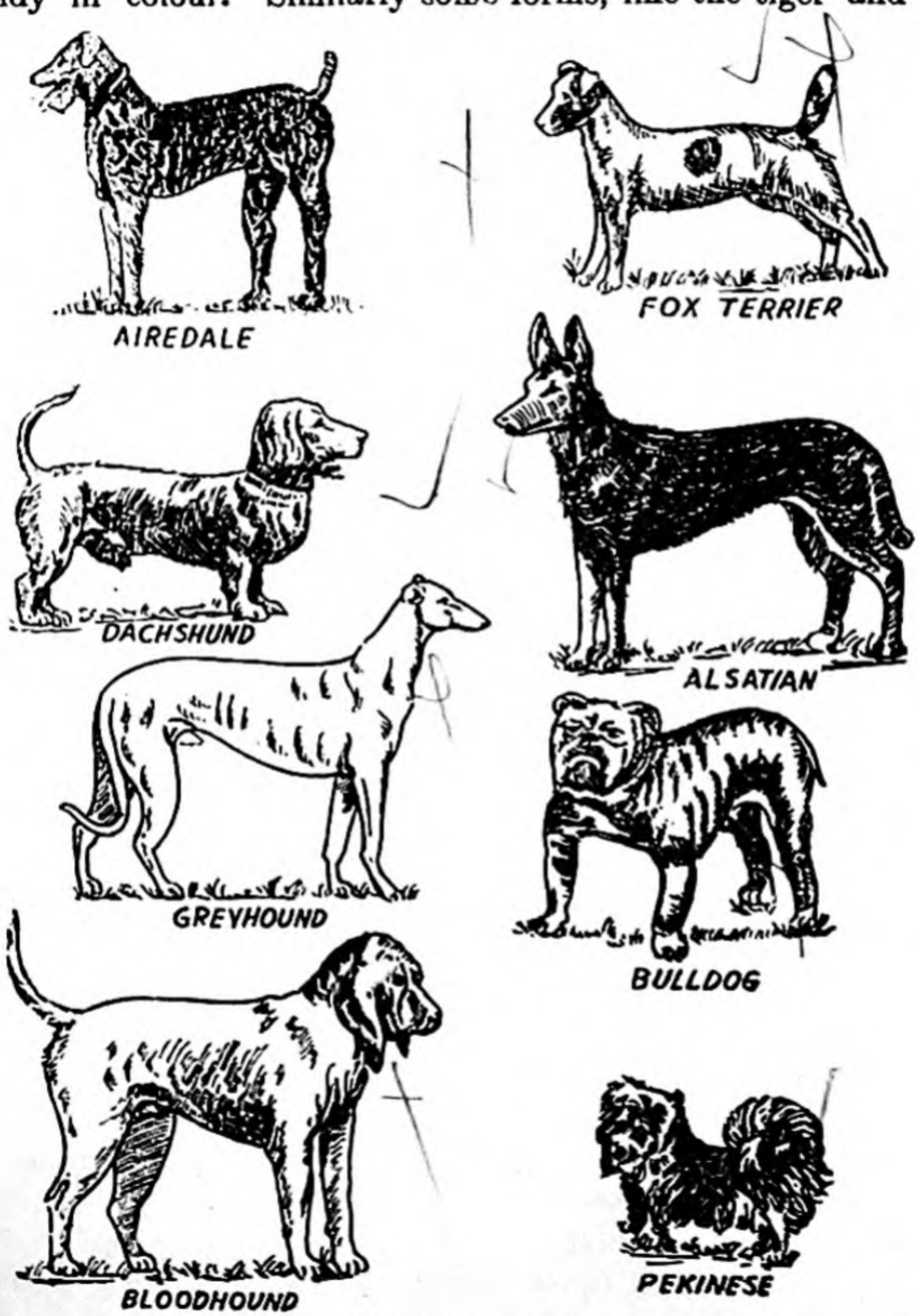

Fig. 218. A few of the common breeds of dogs. (From Beadnell).

leopard, are striped or spotted to harmonize with their surroundings. The marine forms found on the surface of the sea are transparent. Insects provide, excellent examples of protective resemblance. The stick-insect (Fig. 219) just looks like a dry twig, and the leaf-insect like a green leaf. The Indian leaf-butterfly, *Kallima* (Fig. 220), has reached perfection in protective resemblance. The upper surface of the wings is brightly coloured but the under surface, when the wings are folded over the body, resembles a dry leaf. It shows all the parts of a leaf such as stalk, midrib, veins and even black rust spots.

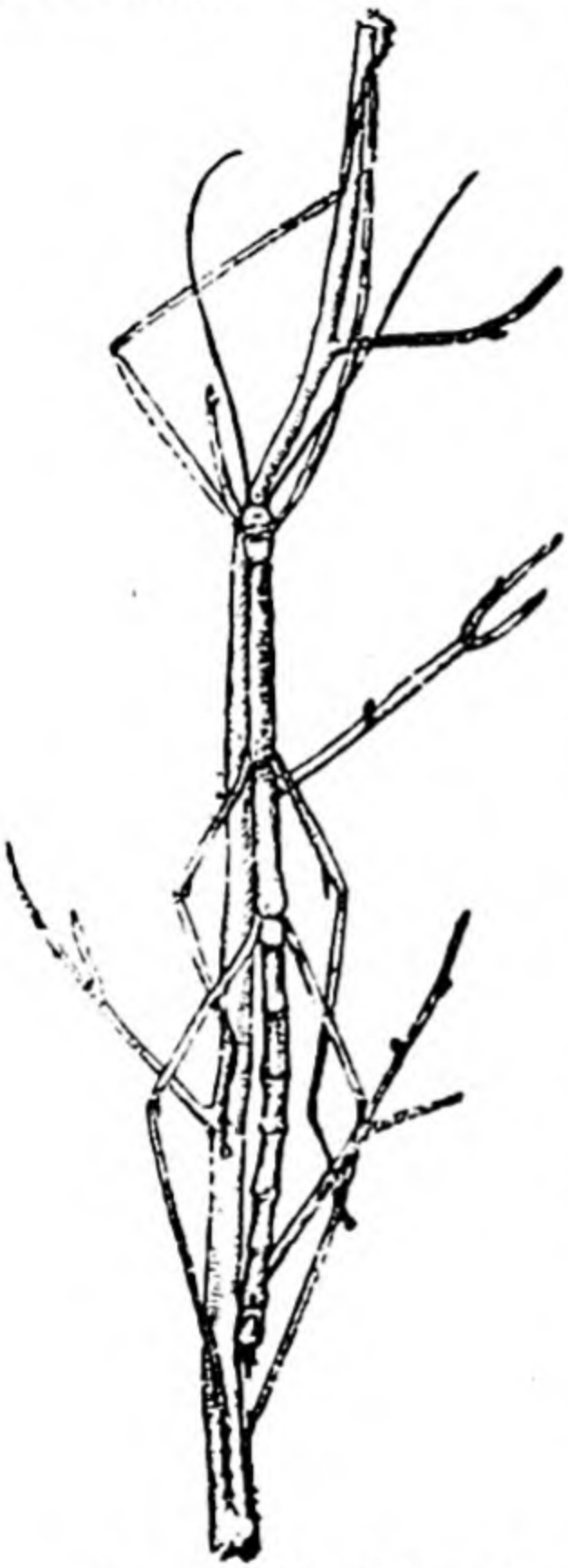

Fig. 219. Stick-insect.

Another type of resemblance, known as *mimicry*, is found between two organisms in forms, colour, attitude or action, which prevents notice or advertises an apparent, but not real, harmfulness. There are certain butterflies which are tasteful to birds and there are others which are distasteful. Some of the tasteful species bear a superficial resemblance to distasteful ones and, therefore, are not attacked by birds, which mistake them for the distasteful species. Similarly many stingless flies resemble stinging bees and wasps.

The phenomena of protective resemblance and mimicry are special kinds of adaptations which can be explained

by the theory of natural selection. They were produced, like other adaptations, by the accumulation of useful variations through many generations.

Fig. 220. Leaf-butterfly (*Kallima*).

Objections to the Theory of Natural Selection.— Natural selection is universally admitted as the chief factor in evolution but not the sole factor, in view of the following objections :—

(1) Natural selection operates only on small variations. It is difficult to imagine how a slight variation in the beginning, in all cases, can be of advantage to its possessor in the struggle for existence and have selection value. There are many organs, such as the vertebrate eye or the electric organs of the electric ray, which are of apparent advantage only in the perfected condition. The same is true of the numerous cases of protective resemblance and mimicry. It is doubtful if a slight

variation in the wings of the ancestor of *Kallima*, the leaf-butterfly, could deceive its enemies and thus confer any advantage on it for selection.

(2) Over specialization of organs, such as the huge antlers of the extinct Irish deer, does not appear to be the result of natural selection, for it is inconceivable that natural selection would operate beyond the limit of greatest usefulness and thus cause an organ to become a hindrance rather than a help. In fact it is now generally believed that many forms in the past, such as the giant reptiles, became extinct due to over specialization.

(3) It is difficult to account for the origin of complex co-ordinated structures on the basis of natural selection. For example in the evolution of the wings of a bird we have to suppose that all its component parts, such as the skin, muscles, bones, ligaments, blood vessels and nerves, simultaneously varied in the same direction. The chances of such a thing happening appear to be small.

(4) The power to regenerate lost parts possessed by certain animals cannot be satisfactorily explained by natural selection. Many lizards can regenerate their lost tails. A little power of regeneration would confer no particular advantage on them. On the othe hand, if the tails are at all involved in the struggle for existence, all the lizards without tails would be eliminated before any regeneration took place.

It is, thus, evident that there are difficulties in the way of accepting the theory of Natural Selection as a complete explanation of organic evolution. As Darwin himself admitted "Natural selection has been the main but not the exclusive means of modification".

Mutation Theory of De Vries. Hugo de Vries (Fig. 221), a Dutch botanist, was born in 1848 and died in 1935. He was

the Director of Botanical Gardens at Amsterdam. His main experiments were performed on the evening primrose (*Oenothera lamarckiana*), which was found growing wild near Amsterdam. He noticed in these plants, in addition to the normal progeny with fluctuating variations, a few individuals differing markedly from the type in several characters. By experiments he discovered that they bred true. On the basis of these and other experiments he formulated his *Mutation theory*, which was published in 1901.

Fig. 221.—Hugo de Vries.

According to the Mutation theory new species arise not by the accumulation of small variations but by sudden and often marked changes, called *mutations*, which may affect a number of characters, and which are inherited. A new species may, thus, arise in a single generation. To quote the words of De Vries himself "According to the theory of mutation, species have not arisen gradually as a result of selection operating for hundreds, or thousands, of years but discontinuously by sudden, however small, changes. In contradistinction to fluctuating variations which are merely of a *plus* or *minus* character the changes which we call mutations are given off in almost every manner of new direction. They only appear from time to time, their periodicity being

probably due to perfectly definite but hitherto undiscovered causes. From this passage it is clear that, whereas, according to the theory of natural selection evolution is a continuous and gradual process, according to the mutation theory it is a discontinuous or jerky process. Mutations do not fluctuate on the plus or minus side of an average condition of a character but follow new and varied lines, without showing any tendency towards progress in a particular direction. The theories of natural selection and mutation agree with each other so far as the struggle for existence, and the selection and inheritance of useful variations are concerned, for natural selection operates in both cases, in the one on fluctuations and in the other on mutations.

The mutation theory, as compared to the theory of natural selection, offers a much quicker method for the formation of new species. It overcomes some of the objections raised against the theory of natural selection, particularly those pertaining to the utility of small initial variations in the struggle for existence. But it can hardly explain the production of all the marvellous adaptations found both in plants and animals. For instance, the mutual adaptation, exhibited by the position of the nectaries of certain flowers and the length of the proboscis in the insects which visit them, appears to have resulted from the accumulation of small variations, side by side in the flowers and the insects, under the influence of natural selection rather than from the occurrence of sudden and discontinuous variations.

Conclusion. After examining critically and objectively the merits of each of the three theories just discussed, we are led to the conclusion that none of them can claim to offer a complete explanation of organic evolution. There is no doubt that *most* of the facts of evolution can be reasonably explained by Darwin's theory of Natural Selection, but unfortunately *not all* of them. While the Lamarckian theory and the Mutation

theory of De Vries have failed to provide a satisfactory explanation of evolution, the former due to the unproved inheritance of acquired characters and the latter to the apparent rarity of mutations, they do seem to cover up some of the shortcomings of the theory of Natural Selection. It, therefore, appears that a reconciliation between these apparently conflicting theories will take us nearer the truth. But it may still require a long time to apprehend the whole truth about organic evolution. As Whitman said in 1904, "The problem of problems of biology today, the problem which promises to sweep through the present century as it has the past one, with cumulative interest and correspondingly important results, is the one which became the life-work of Charles Darwin, and which cannot be better or more simply expressed than in the title of his epoch-making book, "*The Origin of Species.*"

GLOSSARY

Abdomen. The region of the trunk posterior to the thorax.

Abdominal. Pertaining to the abdomen.

Abductor. A muscle that draws a part away from the median line.

Aboral. Opposite the mouth.

Absorption. The passage of nutritive and other fluids into living cells

Accommodation. The adjustment of the eye to distinct vision at different distances.

Acoelomate. An animal without a coelom.

Acquired Character. A character developed during the life of an individual owing to the environment or a functional cause.

Adaptation. The fitness of a structure, function, or entire organism for a particular environment ; the process of being so fitted.

Adductor. A muscle that draws a part towards the median line.

Adipose. Pertaining to fat.

Adrenal. A ductless gland situated near the kidney.

Adrenalin. Hormone secreted by the adrenal glands.

Aerial. Living or moving in the air.

Afferent. Incoming, toward a centre.

Alimentary. Pertaining to food, digestion, or the digestive tract.

Allantois. An embryonic membrane in land vertebrates, primarily for respiration.

Allelomorphs. Genes responsible for alternative expressions of a character, similarly located in a pair of homologous chromosomes.

Alternation of Generations. The alternation of sexual and asexual generations in the life-history of an organism.

Alveolus. A small cavity or pit, as a tooth-socket, or a minute terminal air sac in a lung.

Ambergris. A substance produced in the stomach of a sperm-whale and used in the manufacture of perfumes.

Amino Acids. Components of proteins. Organic acids in which one hydrogen atom is replaced by the amino group (NH_2,.

Amitosis. Direct cell-division which does not involve formation of chromosomes or a spindle.

Amnion. An embryonic membrane in land vertebrates serving for the protection of the embryo.

Amoeboid. A type of movement resembling that of *Amoeba*.

Amphiaster. A figure formed in mitotic cell-division, consisting of two asters connected by the spindle.

Amphibious. Capable of living either on land or in water, as a frog.

Amphicoelous. Concave at both ends, as the centrum of some vertebrae.

Amphimixis. Union of egg and sperm nuclei to form a zygote; mingling of the germ-plasm of two individuals.

Amplexus. The sexual embrace assumed by amphibians during mating.

Ampulla. A small membranous sac.

Amylolytic. Ferments which convert starches into sugar.

Amylopsin. An enzyme produced by the pancreas, which changes starches to sugar.

Anabolism. The building up process in metabolism.

Analogous. Similar in function.

Anaphase. The stage in mitosis when the chromosomes move towards the centrosomes.

Anatomy. The structure of organisms, especially as revealed by dissection.

Animal Pole. That pole of an egg toward which the protoplasm is accumulated.

Antennae. A pair of appendages on the head of an arthropod, sensory in function.

Anterior. In front.

Anthropoid. Man-like.

Antitoxin. A substance in the body which neutralizes a poison or toxin.

Anus. The terminal opening of the alimentary canal.

Aorta. A large artery carrying blood away from the heart.

Appendix. A finger-like process at the end of the caecum.

Apterous. Wingless.

Aquatic. Pertaining to or living in water.

Arboreal. Pertaining to or living in trees.

Archenteron. The primitive digestive cavity of a metazoan embryo.

Artery. A vessel carrying blood away from the heart.

Asexual. Not related to sex, or having no sex.

Assimilation. The incorporation of food into living protoplasm.

Aster. The rays which surround the centrosomes in a mitotie figure.

Asymmetrical. Without symmetry.

Auditory. Pertaining to the organ or sense of hearing.

Auricle. A chamber in the heart which receives blood.

Bilateral Symmetry. Having the sides symmetrical.

Bile. The secretion of the liver in vertebrates.

Binary Fission. The division of a cell, especially a unicellular organism, into two daughter-cells.

Binomial Nomenclature. The scientific method of naming organisms by two words, the first indicating the genus and the second, the species.

Biogenesis. The conception that living things can arise only om pre-existing living things.

Biology. The science of life and living things.
Biramous. Having two branches.
Blastocoele. The cavity of a blastula ; the segmentation cavity.
Blastopore. The opening to the exterior from the enteric pouch of a gastrula.
Blastostyle. The individual of a hydroid colony which forms medusa buds.
Blastula. The hollow sphere of cells resulting from cleavage of an egg.
Blood Corpuscles. Detached cells present in the plasma of the blood.
Brachial. Referring to the fore-limb.
Branchial. Referring to gills.
Bronchus. One of the larger divisions of the trachea conveying air into the lungs.
Buccal Cavity. Mouth-cavity.
Budding. The production of offspring by the growing out of part of the body.
Caecum. A blind pouch of the intestine.
Calcareous. Composed of calcium carbonate.
Capillary. A minute, thin-walled vessel that connects an artery and a vein.
Carapace. A hard dorsal covering of a body.
Carbohydrate. An organic compound composed of carbon, hydrogen and oxygen, with two atoms of hydrogen to one of oxygen.
Cardiac. Pertaining to the heart.
Carnivorous. Flesh-eating.
Carpus. Wrist-bones.
Cartilage. An elastic animal tissue.
Caterpillar. The larva of butterflies and moths.
Caudal. Pertaining to the tail.
Cell. A mass of protoplasm containing a nucleus.

Centriole. The small central granule of a centrosome.

Centrosome. A small differentiated region in the cytoplasm of a cell containing the centriole.

Centrosphere. The spherical area around the centriole.

Cephalic. Pertaining to the head.

Cephalothorax. Combined head and thorax.

Cerebral. Pertaining to the brain, or to the cerebrum.

Cervical. Pertaining to the neck.

Character. Any feature or property of an organism.

Chitin. A horny snbstance forming the outer covering of many arthropods.

Chordate. An animal having a temporary or permanent dorsal notochord.

Chlorophyll. The green pigment of plants, involved in photosynthesis.

Chromatin. A substance in the nucleus that becomes deeply stained by certain dyes and which is believed to be the bearer of inheritable tendencies.

Chromosome. One of the small bodies into which the chromatin of a cell nucleus resolves itself during mitosis.

Cilia. Tiny hair-like projections from the surface of a cell, which have the power of rapid, co-ordinated vibration.

Class. A main sub-division of a phylum.

Cleavage. Division of the zygote into cells.

Cloaca. The common cavity into which the intestinal, urinary and genital canals open in most chordates below the mammals.

Cnidoblast. A cell in a coelenterate in which develops a nematocyst.

Cnidocil. A small trigger-like process for projecting the thread from the cnidoblast.

Coagulation. The change from a fluid to a thickened, semi-solid condition, as in the clotting of blood.

Cocoon. A protective covering for a mass of eggs, a larva or pupa, or even an adult animal.

Coelom. A body-cavity lined with mesoderm.

Coenosarc. Inner granular tissue of the tubular branches of a hydroid.

Cold-blooded. Having blood at about the same temperature as the environment.

Colloid. A state of matter in which particles larger than single molecules are suspended in a liquid.

Colony. An association of individuals descended from a common ancestor and remaining in organic connection.

Commensalism. A mutually beneficial association of two species of animals.

Compound Eye. One composed of numerous facets, or separate visual elements.

Conjugation. The temporary union of two unicellular organisms during which chromatin material is interchanged.

Conjugant. One of the two conjugating individuals.

Contractile Vacuole. A reservoir in unicellular organisms in which water and waste products collect and are periodically expelled to the exterior.

Co-ordination. Acting together of parts of an organism so as to bring about physiological balance.

Copulation. Temporary sexual union involving the transference of spermatozoa from the male to the female.

Cortex. The outer layer of certain organs, notably of the brain.

Cranial. Pertaining to the part of the skull which encloses the brain.

Cranial Nerves. Nerves which arise from the brain.

Crop. An enlargement of an anterior part of the alimentary canal, especially in insects and birds.

Cross-fertilization. The fertilization of an egg of one individual by a spermatozoon of another individual.

Cutaneous. Pertaining to the skin.

Cuticle. The outermost lifeless layer of the skin.

Cyclosis. The circulatory movements of protoplasm within a cell.

Cyst. A resistant envelope formed around an organism during unfavourable conditions or reproduction.

Cytology. The science of cell-structure.

Cytoplasm. The protoplasm of a cell outside the nucleus and within the cell-membrane.

Darwinism. Darwin's theory that the origin of species has taken place by natural selection.

Dendrite. The process of a nerve cell that conducts impulses to the cell-body, often branched.

Dermal. Pertaining to the skin, especially the inner connective tissue layer of vertebrate skin.

Dermis. The deeper portion of the skin beneath the epidermis in a vertebrate, derived from mesoderm.

Diffusion. The spreading of molecules of one substance among those of another.

Digestion. Chemical simplification of food so that it can be absorbed and utilized.

Dihybrid. The offspring of parents that differ in two characters.

Dimorphism. Existing under two distinct forms.

Dioecious. With the male and female reproductive organs in separate individuals.

Diploblastic. Derived from two embryonic germ layers, ectoderm and endoderm.

Diploid. The double set of chromosomes that occur in all cells except the mature egg and spermatozoon.

Distal. Located away from the body or point of attachment.

Diurnal. Pertaining to the daytime.

Division of Labour. Allocation of special functions to special parts which co-operate toward the unity of the whole.

Dominant Character. A character from one parent that manifests itself in the offspring to the exclusion of a contrasted (recessive) character from the other parent.

Dorsal. Toward or pertaining to the back or upper surface.

Ductless Gland. A gland that secretes a substance (hormone) directly into the blood rather than by ducts.

Ecdysis. The shedding of the cuticular covering of an arthropod.

Ecology. The study of an organism in relation to its environment.

Ectoderm. The outer germ layer or cell layer of an early embryo.

Ectoparasite. A parasite that lives on the outside of the body of its host.

Ectoplasm. The surface layer of cytoplasm of a cell.

Efferent. Conveying outward or away.

Egest. To discharge unabsorbed food or residues from the digestive tract.

Embryo. The stage in the development of an organism still contained in the egg membrane or in the body of the mother.

Embryology. The study of the early developmental stages of an organism.

Encystment. The formation of a resistant covering or cyst around an organism.

Endocrine gland. See Ductless Gland.

Endoderm. The inner layer of cells in the gastrula which gives rise to the lining of the digestive tract.

Endomixis. Nuclear reorganization in some Protozoa without conjugation.

Endoparasite. A parasite which lives inside the body of its host.

Endoplasm. The inner cytoplasm surrounding the nucleus.

Endopodite. The inner of the two branches of a biramous appendage.

Endoskeleton. A skelton within the body of an animal.

Enteron. The digestive cavity.

Enteric. Pertaining to digestion.

Entomology. The study of insects.

Environment. The conditions surrounding an organism in its habitat.

Enzyme. An organic substance secreted by cells that brings about chemical changes without undergoing any change itself.

Epidermal. Pertaining to the outer layer of the skin.

Epithelium. A type of cell layer that covers external and internal surfaces.

Evolution. The theory that existing living forms have been derived by gradual modification from earlier and simpler forms.

Excretion. The elimination of waste products of metabolism. A waste product.

Exopodite. The outer of the two branches of a biramous appendage.

Exoskeleton. A skeleton on the outside of an animal.

Extensor. A muscle that straightens out a joint.

Extinct. No longer in existence.

Extracellular. Outside the cell.

Family. A main sub-division of an order.

Fauna. The total of the animal life of a given region or period.

Fertilization. The union of female and male gametes (egg and sperm) to form a zygote.

Fission. The division of a cell or organism into two or more parts.

Flagellum. A long, whip-like process of a cell used as an organ of locomotion.

Flexor. A muscle that serves to bend a limb or part.

Foramen. An opening in a bone, membrane or partition.

Fossil. Anything dug out of the earth pertaining to a prehistoric organism.

Free-living. Not attached or parasitic ; capable of independent movement and existence.

Function. The activity or action of any part of an organism.

Gamete. A mature reproductive or germ cell, either male (sperm) or female (ovum).

Gametocyte. A cell capable of producing one or more gametes.

Gametogenesis. The process of formation of mature germ cells or gametes.

Ganglion. A mass of nerve-cells consisting principally of their bodies.

Gastric. Pertaining to the stomach.

Gastrula. A stage in animal development in which the embryo consists of a two-layered sac, ectoderm and endoderm, enclosing the enteric cavity which opens to the exterior by the blastopore.

Gene. Something in a chromosome responsible for the development of a character. A factor or hereditary determiner.

Genetics. The science of heredity.

Genital. Pertaining to the reproductive organs.

Genus. A main sub-division of a family.

Germ Cell. A reproductive cell in a multicellular organism.

Germ Layer. One of the fundamental cell layers (ectoderm, mesoderm, endoderm) in the embryo from which tissues and organs of the adult are formed.

Germ-plasm. The physical basis of inheritance ; the chromatin. Contrasted with soma or somatoplasm. Germ.

Gestation. The period between fertilization and the birth of a mammal.

Gill. The breathing organ of an animal that lives in the water.

Gizzard. A muscular part of the alimentary canal.

Gland. Any cell, or group of cells, that manufactures a product for the use of the organism.

Glomerulus. A ball-like coil of capillaries at the enlarged end of each urinary tubule in the kidney of higher vertebrates.

Glottis. The opening from the pharynx into the trachea.

Glycogen. The form in which sugar is stored in the liver and muscle cells.

Golgi Bodies. Special bodies in the cytoplasm of certain cells.

Gonad. Reproductive organ ; testis or ovary.

Gonotheca. Transparent sheath, or exoskeleton, of the reproductive individuals of a hydroid colony.

Gregarious. Habitually living in groups, flocks, etc., of numerous individuals.

Habitat. The environment in which an organism normally lives.

Haemal. Pertaining to the blood.

Haemocoel. Body-cavity containing blood.

Haemoglobin. The red substance in the blood that carries oxygen.

Haploid. The single or halved number of chromosomes as found in mature germ cells.

Hepatic. Pertaining to the liver.

Herbivorous. Plant-eating, as opposed to carnivorous.

Heredity. The transmission of characters from parents to offspring.

Hermaphrodite. An individual in which both male and female reproductive organs are present.

Hibernation. Passing the winter in a quiescent and torpid condition.

Histology. The study of microscopic structure of tissues.

Holoblastic. Cleavage in which the egg divides completely into cells.

Holophytic. Plant-like nutrition involving photosynthesis of simple inorganic substances.

Holozoic. Animal-like nutrition involving the ingestion and digestion of complex organic compounds.

Homologous Chromosomes. The members of a pair of chromosomes having relatively similar structure and value, one from each parent.

Homology. Fundamental structural similarity, regardless of function.

Hormone. A secretion of an endocrine gland that effects vital body functions in higher animals.

Host. An organism within or upon which a parasite lives.

Hybrid. The offspring of two parents that differ in one or more heritable characters.

Hydranth. A feeding polyp of a hydroid colony.

Hydrotheca. Vase-like expansion of the exoskeleton, or perisarc, about a hydranth.

Imago. An insect in its final adult, sexually mature, and usually winged state.

Immunity. Resistance of the body to infection by disease-producing organisms.

Incubation Period. The interval of time between the infection and the appearance of the symptoms of the disease.

Ingestion. The act of taking in food.

Inheritance. The sum of all characters that are transmitted by the germ cells from generation to generation.

Insectivorous. Insect-eating.

Instar. A period between moults in an insect larva.

Instinct. The natural impulse by which animals are guided apparently independent of reason or experience.

Integument. The outer covering of the body.

Intercellular. Between or among cells.

Internal Secretion. A secretion that enters the blood or lymph directly and not through a duct.

Intracellular. Within a cell.

Invagination. Sinking or growing in of a portion of the surface of a hollow body.

Invertebrate. Animal without a notochord or a vertebral column.

Involution. Rolling inward or turning in of cells over a rim, as in gastrulation of frog's embryo.

Irritability. The power of responding to stimuli.

Joint. A place of union between two separate bones or other hardened structures.

Katabolism. The destructive phase of metabolism.

Labial. Pertaining to lips.

Lamarckism. Essentially the doctrine of the inheritance of acquired characters as a factor in evolution.

Lamella. A thin sheet-like layer.

Larva. An immature stage in the life-history of certain animals, usually active and differing widely in appearance from the adult.

Leucocyte. A white blood corpuscle.

Levator. A muscle which raises or elevates a part.

Lingual. Pertaining to the tongue.

Lymph. Plasma and white blood corpuscles that bathe the tissue cells.

Lymphatic. A vessel which conveys lymph.

Macrogamete. A female sex cell or egg cell.

Macromere. One of the large cells in the cleavage stages of certain animals.

Macronucleus. The larger nutritive nucleus of certain Protozoa as distinguished from the smaller reproductive micronucleus.

Maggot. The footless larva of certain insects.

Marine. Of or pertaining to the sea.

Mastication. The act of chewing food with the teeth.

Maternal. Pertaining to a mother.

Maturation. The maturing of the sex cells involving the reduction of chromosomes to one half.

Meiosis. The reduction division in the maturation of germ cells.

Melanin. Black, or nearly black, pigment.

Meridional. Lines or planes running from pole to pole.

Meroblastic. Cleavage of an egg in which it is only partly divided into blastomeres.

Mesentery. A double sheet of tissue attaching the alimentary canal to the body-wall in vertebrates ; thin sheet of tissue connecting the stomodaeum to the body-wall in certain coelenterates.

Mesoderm. A layer of cells that develops in the embryo between the outer ectoderm and inner endoderm.

Mesogloea. The jelly-like substance that develops between the ectoderm and endoderm in coelenterates.

Mesothorax. The middle of the three segments of the thorax of an insect.

Metabolism. The physico-chemical processes within a cell that build up and break down protoplasm.

Metagenesis. The alternation of sexual and asexual generations in the life-history of an organism.

Metamere. One of a linear series of similar divisions into which the bodies of certain animals are divided. Segment.

Metamerism. The existence of metameres in the body of an animal.

Metamorphosis. Pronounced change in form from one stage of development to another, as of a larva to an adult.

Metaphase. The phase of mitosis when the chromosomes, having arranged themselves around the equator of the spindle, are divided each into two.

Metathorax. The posterior segment of the thorax in insects.

Metazoa. Animals consisting of many cells, differentiated to form tissues.

Micronucleus. The smaller, reproductive nucleus of certain Protozoa.

Migration. Movement of organisms, usually in groups, from one region to another.

Mitochondria. Bodies in the cytoplasm of more or less regular shape that appear to play a part in metabolism.

Mitosis. Indirect cell division involving the formation and splitting of chromosomes and their equal distribution to daughter nuclei.

Moulting. The shedding of an outer covering.

Monoecious. With the male and female reproductive organs in the same individual. Hermaphrodite.

Monohybrid. The offspring of parents differing in one character.

Morphology. The study of the form of animals and plants.

Morula. The globular mass of cells formed by cleavage of the egg in the early development of many animals.

Mutation. Abrupt and heritable variation of a character.

Nasal. Pertaining to the nose or nostrils.

Natural Selection. The selection in nature of those individuals best fitted to survive in a particular environment.

Nematocyst. A stinging thread thrust from a sac-like cell.

Nephridium. An excretory organ, usually tubular.

Nephridiopore. The opening at the outer end of a nephridium.

Nephrostome. The ciliated opening at the inner end of a nephridium.

Neural. Pertaining to a nerve or to the nervous system.

Neuron. A nerve cell consisting of the cell-body and its cytoplasmic processes.

Nocturnal. Active by night.

Notochord. The cellular rod characteristic of the Chordata, which in the Vertebrata is replaced by the vertebral column.

Nucleolus. A well-defined body within the nucleus in most cells.

Nucleus. A specialized protoplasmic body within the cell that contains the chromatin.

Nutrition. The process involved in obtaining food and transforming it into living substance.

Nymph. In insects, an immature miniature replica of the adult except for wings and reproductive organs.

Ocellus. A simple eye, as in an insect.

Ocular. Pertaining to the eye.

Olfactory. Pertaining to the sense of smell.

Ommatidium. A rod-like unit in a compound eye.

Omnivorous. Eating all kinds of food.

Ontogeny. Development of the individual.

Oocyst. Encysted zygote.

Oocyte. The female egg before maturation.

Oogenesis. The development of the mature egg from a primordial germ cell.

Operculum. The plate covering the gills of a bony fish ; also the plate covering the opening of some snail shells.

Optic. Pertaining to vision or sight, or to the eyes.

Oral. Pertaining to the mouth.

Order. A main sub-division of a class.

Organ. A combination of tissues for the performance of a particular function.

Organism. A member of the animal or vegetable kingdom.

Osmosis. Diffusion through a semi-permeable membrane.

Ovary. A gonad in which eggs, or ova, multiply and grow.

Oviduct. A duct through which the egg passes from the ovary.

Oviparous. Egg-laying.

Ovum. The female gamete or egg.

Oxidation. The combination of any substance with oxygen.

Palaeontology. The science of extinct animals and plants represented by fossil remains.

Parasite. An organism that lives on or within, and at the expense of, another organism.

Paternal. Pertaining to a father.

Pelagic. Pertaining to the open sea, away from the shore.

Pentadactyle. Having five fingers or toes.

Pericardium. Peritoneum lining the pericardial cavity containing the heart.

Peristalsis. Rhythmical contractions of the wall of the alimentary canal which force the food along.

Peristome. The region surrounding the mouth.

Peritoneum. Membrane lining coelom of vertebrates.

Pharyngeal. Pertaining to the pharynx.

Pharynx. Region of alimentary canal between buccal cavity, or mouth, and oesophagus. Throat.

Photosynthesis. Process by which complex compounds are built up from simple elements through the energy of sunlight absorbed by chlorophyll.

Phylogeny. The ancestral history of the race.

Phylum. A main sub-division of the animal kingdom.

Physiology. The study of the functions of animals and plants.

Pigment. Colouring matter.

Placenta. An organ in mammals that attaches the embryo to the mother and through which nutritive, respiratory and excretory materials are interchanged.

Plasma. The liquid part of the blood.

Polar Bodies. The minute abortive cells that are formed by the female germ cells during maturation.

Predaceous. Capturing living animals for food.

Prehensile. Fitted for grasping or holding.

Procoelous. Concave in front, as the centrum of a vertebra.

Prophase. The first stage in mitosis during which chromosomes appear and form an equatorial plate.

Proctodaeum. The posterior part of the alimentary canal formed by an ingrowth of the ectoderm.

Protective Resemblance. A resemblance of an animal to its environment which tends to make it inconspicuous.

Protein. An organic compound containing carbon, hydrogen, oxygen and nitrogen, and which is an essential constituent of protoplasm.

Proteolytic. Ferments which act on proteins.

Prothorax. The anterior segment of the thorax of insects.

Protoplasm. The living substance of which plants and animals are composed.

Protopodite. The basal part of the typical crustacean appendage from which arise the endopodite and exopodite.

Protozoa. Unicellular animals.

Proximal. Toward or nearer the place of attachment ; opposite to distal.

Pseudopodium. Temporary protoplasmic projections for locomotion, feeding, etc.

Pulmonary. Pertaining to the lungs.

Pupa. The inactive stage in the development of some insects, occurring between the larval and adult stages.

Pylorus. The opening from the stomach into the intestine.

Radial Symmetry. Having similar parts arranged around a common cental axis.

Recapitulation Theory. The theory that the individual in its own life-history passes through, in modified form, the stages in the evolution of its race.

Recessive Character. A character from one parent that remains undeveloped in the offspring when associated with the corresponding dominant character from the other parent.

Rectal. Pertaining to or connected with the rectum.

Reduction Division. The division of the maturing germ cells by which the number of chromosomes is reduced to one half.

Reflex Action. An automatic response to a stimulus without the intervention of the will.

Regeneration. The replacement of lost parts.

Renal. Pertaining to the kidneys.

Reproduction. The production by an organism of others of its kind.

Respiration. The exchange of oxygen and carbon dioxide between an organism and its environment, or between the blood and different tissues.

Response. The reaction of an organism to a stimulus.

Rudimentary. A part or organ that is not fully developed.

Secretion. The production by a cell or multicellular gland of a substance of use to the organism; also the substance produced.

Sedentary. Remaining in one place.

Segment. One part of a metameric animal.

Seminal Receptacle. A sac in the body of a female animal in which the sperms are stored until used. Spermatheca.

Seminal Vesicle. A sac in the body of a male animal in which sperms are stored until transferred to the female.

Sense-organ. An organ sensitive to a particular kind of stimulus.

Septum. A dividing wall or partition between two cavities or structures.

Serum. The liquid part of blood that separates from a clot and contains no cells or fibrin.

Sesamoid Bone. Bone developed within tendon of a vertebrate, occurring especially in mammals, *e.g.*, patella (knee-cap).

Sessile. Attached directly by the base; not raised upon a stalk.

Seta. A fine bristle, used in the annelids as a locomotor structure.

Siliceous. Containing silica.

Sinus. A cavity of bone or other tissue.

Siphon. Usually a tube through which water or other fluids pass.

Skeleton. The hard supporting parts of an animal body.

Skull. The bones of the head in a vertebrate.

Solitary. Living alone, not in colonies or groups.

Soma. Body cells as contrasted with germinal cells

Somite. A serial segment ; a metamere.

Spawn. The eggs of certain species of oviparous animals.

Special Creation. The theory that each species of animal was specially created and did not arise by the process of organic evolution.

Species. The unit in classification of animals or plants.

Spermary. A gonad producing sperm cells.

Spermatozoon. The functional sex cell of the male ; sperm.

Spermatid. A male sex cell after the second maturation division in spermatogenesis, before its metamorphosis into a spermatozoon.

Spermatocyte. A male sex cell during the period of maturation in spermatogenesis.

Spermatogenesis. The production of spermatozoa from primordial germ cells.

Spermatophore. A mass of spermatozoa usually enclosed in a membrane or capsule.

Sphincter. A muscle surrounding an opening which, by its contraction, it closes.

Spicule. A minute limy or silicious crystal-like object, embedded in the tissues of an animal, which serves to stiffen or support the body or part.

Spinal. Pertaining to the backbone or spinal column.

Spiracle. In insects, one of the openings into the tracheal tubes ; in sharks, a modified and usually non-functional gill-slit ; in amphibians, the external opening of a chamber on the inner wall of which are the gill-slits.

Spireme. The chromatin threads during the prophase of mitosis that seem to form a continuous coil.

Spore. A cell in a resistant covering, capable of developing independently into a new individual.

Sporulation. The production of spores by a protozoan.

Statocyst. An organ of equilibrium in many invertebrates.

Statolith. A solid body within a statocyst.

Steapsin. An enzyme in the pancreatic secretion which changes fats to fatty acids and glycerine.

Sternal. Pertaining to the sternum.

Stigma. An eye spot in protozoans ; a spiracle in an insect.

Stimulus. A change within an animal or in its environment that brings about a response.

Stomadaeum. The anterior part of the alimentary canal formed by an ingrowth of the ectoderm.

Stroma. Mesodermal supporting tissues of an organ.

Suture. A line of junction.

Symbiosis. An intimate association of two organisms of different species in a practically obligatory and mutually advantageous partnership.

Symmetry. The arrangement of similar parts around an axis or on opposite sides of any plane of the body.

Synapsis. The pairing of homologous chromosomes during maturation of the germ cells.

Symphysis. A union between two parts, usually bones.

Syngamy. The union of two sex cells to form a zygote.

Synkarion. The composite nucleus formed by the union of the nuclei of two gametes.

System. A group of organs that together perform some particular function.

Tactile. Pertaining to the sense of touch.

Taxonomy. The science of classification of organisms.

Telophase. The last phase of mitosis during which daughter nuclei are formed.

Tendon. A connective tissue band attaching a muscle to a bone.

Tentacle. An elongate flexible appendage usually near the mouth.

Terrestrial. Living on land.

Theory. An explanation of natural phenomena that remains to be proved.

Thorax. In insects, the middle of the three divisions of the body ; in mammals, the chest cavity.

Thoracic. Pertaining to the thorax.

Tissue. A group of cells having essentially the same structure and function.

Triploblastic. Derived from three embryonic germ layers, ectoderm, mesoderm and endoderm.

Trochophore. An invertebrate larva, commonly pear-shaped and with an equatorial band of cilia.

Trophozoite. Growing and feeding stage in the life-history of a sporozoan.

Tympanum. A vibrating membrane involved in hearing ; the eardrum or tympanic membrane.

Typhlosole. A longitudinal fold of the wall projecting into the cavity of the intestine of some invertebrates.

Ungulate. Having hoofs.

Urea. A nitrogenous substance resulting from animal metabolism.

Ureter. A tube carrying urine from kidney to the cloaca or to the urinary bladder.

Urinogenital. Pertaining to the urinary and genital systems.

Urethra. The duct from the urinary bladder to the external surface.

Uterus. A dilated posterior portion of an oviduct in which eggs may be retained for development.

Vacuole. A minute cavity within a cell, usually filled with some liquid product of protoplasmic activity.

Vagina. In female mammals, a passage leading from the uterus to the exterior.

Variations. Differences in structure or function that occur among the individuals of a species.

Variety. One of the divisions of a species.

Vascular. Pertaining to vessels, especially blood vessels.

Vas deferens. The duct leading from the testis to the outside.

Vas efferens. One of a number of small ducts interposed between the testis and the vas deferens.

Vegetative. Pertaining to nutrition.

Vein. A vessel conveying blood toward the heart.

Ventral. Of or pertaining to the lower side of an organism, organ, or part ; opposite to dorsal.

Ventricle. A chamber in the heart from which blood is sent out ; a cavity in the brain of a vertebrate.

Vermiform. Worm-like in form.

Vertebrate. An animal with a backbone or vertebral column.

Vesicle. A small sac, especially one filled with fluid.

Vestigial. Pertaining to structures or organs that were well developed in an animal's ancestors but have become reduced and functionless during the course of evolution

Villus. A minute finger-like projection ; especially those on the intestinal lining of vertebrates.

Viscera. Internal organs of the body, especially those within the abdominal cavity.

Visceral. Pertaining to the viscera.

Visceral Skeleton. The supporting frame-work of the jaws and gill arches and their derivatives, in vertebrates.

Vitelline. Pertaining to yolk.

Viviparous. Producing young in a comparatively advanced stage of development that have been nourished within the mother's body.

Warm-blooded. Having blood at practically a constant temperature regardless of the temperature of the environment.

Yolk. A type of food material stored within the eggs of certain animals.

Zoogeography. The study of the geographical distribution of animals.

Zooid. An individual member of a colony that has been produced by asexual reproduction, notably in coelenterates.

Zoology. The science dealing with animal life.

Zygote. A cell formed by the union of a male gamete with a female gamete.

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